PB-228 351

CONNECTICUT RIVER MICROBIOLOGY, OCTOBER 1965-SEPTEMBER 1969

John D. Buck

Connecticut University
Noank, Connecticut

1 June 1970

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 228 351

ENVIRONMENTAL PROTECTION AGENCY
LIBRARY

SUMMARY REPORT

CONNECTICUT RIVER MICROBIOLOGY
October 1965-September 1969

John D. Buck

MARINE RESEARCH LABORATORY
UNIVERSITY OF CONNECTICUT
NOANK, CONNECTICUT 06340

Contract No. 14-12-177
United States Department of the Interior
Federal Water Pollution Control Administration
1 June 1970

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

FWPCA Review Notice

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

TABLE OF CONTENTS

Table of Contents iii
List of Figures v
List of Tables vii
Acknowledgements viii
I. Introduction 1
    A. Purpose of study 1
    B. Characteristics of CYAPC Plant 2
II. Conclusions 5
III. Summary 7
IV. The Connecticut River 10
    A. General description 10
    B. Water quality 10
    C. Water uses of the Connecticut River 11
        1. Recreational uses 11
        2. Commercial fisheries 15
        3. Commercial navigation 15
        4. Cooling water and waste disposal 16
        5. Future proposed uses 16
V. Logistics of thermal effluent studies 17
    A. Description of sampling area 17
    B. Field sampling 21
    C. Laboratory procedures and determinations. 22
        1. Chemistry 22
        2. Phytoplankton 23
        3. Bacteria 23
VI. Results: October 1965-September 1969 27
    A. Field study 27
        1. Physical characteristics at sampling stations 27
            a. Shoaling 27
            b. Temperature distribution 27
        2. Water Chemistry 31
            a. pH 31
            b. Salinity 39
            c. Dissolved oxygen 39
            d. Nitrate and phosphate 49
            e. Other chemical determinations 58
        3. Phytoplankton 58
        4. Macrobenthic invertebrates 85
        5. Bacteria-quantitative 87
            a. "Total counts" - mesophiles 89
            b. Specific groups 89
                i Amylolytic 89
                ii Lipolytic 89
                iii Proteolytic and acid and base producing bacteria. 89
                iv "Marine" bacteria 96
                v Psychrophiles 97
                vi Thermophiles 97
                vii Anaerobes 110
                viii Pollution-indicating bacteria 110
                ix Miscellaneous groups 117
    B. Laboratory studies - bacteria 130
        1. Generic identification of total count isolates 130
        2. Chemostat studies 144
        3. Study of immediate waters 147
        4. Temperature tolerance of "thermophile" and "psychrophile" isolates. 148

    5. Salinity tolerances of "marine" bacteria 149
    6. Biochemical characteristics of pollution-indicating bacteria. 150
VII. Summary of Allied Research - Essex Marine Laboratory. 153
VIII. Evaluation of study 155
References 157

LIST OF FIGURES

No. Title Page

1. Average gross monthly generating levels of the CYAPC Plant 4
2. General location 18
3. Connecticut River study area 19
4. Approximate extent of shoaling at Station 3. 20
5. Connecticut River temperature (°F); Station 1; Prethermal Period. 29
6. Connecticut River temperature (°F); Station 1; Thermal Period. 30
7. Connecticut River temperature (°F); Station 3; Prethermal Period. 32
8. Connecticut River temperature (°F); Station 3; Thermal Period 33
9. Connecticut River temperature (°F); Station 6; Prethermal Period. 34
10. Connecticut River temperature (°F): Station 6; Thermal Period. 35
11. Connecticut River temperature (°F); Station 7&B; Prethermal Period. 36
12. Connecticut River temperature (°F); Station B; Thermal Period. 37
13. Average seasonal temperatures, Top and Bottom (°F). 1965-1969. 38
14. Connecticut River dissolved oxygen (ppm); Station 1. Prethermal Period. 40
15. Connecticut River dissolved oxygen (ppm); Station 1. Thermal Period. 41
16. Connecticut River dissolved oxygen (ppm); Station 3. Prethermal Period. 42
17. Connecticut River dissolved oxygen (ppm); Station 3. Thermal Period. 43
18. Connecticut River dissolved oxygen (ppm); Station 6. Prethermal Period. 44
19. Connecticut River dissolved oxygen (ppm); Station 6. Thermal Period. 45
20. Connecticut River dissolved oxygen (ppm); Station 7 & B. Prethermal Period. 46
21. Connecticut River dissolved oxygen (ppm); Station B. Thermal Period. 47
22. Average (T&B) nitrate and phosphate; Station 1; Prethermal Period. 50
23. Average (T&B) nitrate and phosphate; Station 1; Thermal Period. 51
24. Average (T&B) nitrate and phosphate; Station 3; Prethermal Period. 52
25. Average (T&B) nitrate and phosphate; Station 3; Thermal Period. 53
26. Average (T&B) nitrate and phosphate; Station 6; Prethermal Period. 54
27. Average (T&B) nitrate and phosphate; Station 6; Thermal Period. 55
28. Average (T&B) nitrate and phosphate; Station 7&B; Prethermal Period. 56
29. Average (T&B) nitrate and phosphate; Station B; Thermal Period. 57
30. Phytoplankton density in the Connecticut River; Station 1; 10/65-10/69. 61
31. Phytoplankton density in the Connecticut River; Station 3; 10/65-10/69 62
32. Phytoplankton density in the Connecticut River; Station 6, 10/65-10/69 63
33A. Comparison of phytoplankton density for surface waters at Stations 1, 3, and 6 during thermal conditions. 69
33B. Comparison of Stations 1 and 3 for 1967 and 1968 during periods of high thermal release. 70
34. Comparison of the Coefficient of Community between phytoplankton and phyco-periphyton; August 20, 1968. 83
35. Mesophiles, no./ml.; Station 1. Prethermal Period. 90
36. Mesophiles, no./ml.; Station 1. Thermal Period. 91
37. Mesophiles, no./ml.; Station 3. Prethermal Period. 92
38. Mesophiles, no./ml.; Station 3. Thermal Period 93
39. Mesophiles, no./ml.; Stations 7&B. Prethermal Period. 94
40. Mesophiles, no./ml.; Station B. Thermal Period. 95
41. Psychrophiles, no./ml.; Station 1. Prethermal Period. 98
42. Psychrophiles, no./ml.; Station 1. Thermal Period. 99

43. Psychrophiles, no./ml.; Station 3. Prethermal Period. 100
44. Psychrophiles, no./ml.; Station 3. Thermal Period. 101
45. Psychrophiles, no./ml.; Stations 7 & B. Prethermal Period. 102
46. Psychrophiles, no./ml.; Station B. Thermal Period. 103
47. Thermophiles, no./ml.; Station 1. Prethermal Period. 104
48. Thermophiles, no./ml.; Station 1. Thermal Period. 105
49. Thermophiles, no./ml.; Station 3. Prethermal Period. 106
50. Thermophiles, no./ml.; Station 3. Thermal Period. 107
51. Thermophiles, no./ml.; Stations 7 & B. Prethermal Period 108
52. Thermophiles, no./ml.; Station B. Thermal Period. 109
53. Coliforms, no./100ml.; Station 1. Prethermal Period. 111
54. Coliforms, no./100ml.; Station 1. Thermal Period 112
55. Coliforms, no./100ml.; Station 3. Prethermal Period. 113
56. Coliforms, no./100ml.; Station 3. Thermal Period. 114
57. Coliforms, no./100ml.; Stations 7 & B. Prethermal Period. 115
58. Coliforms, no./100ml.; Station B. Thermal Period. 116
59. Fecal Coliforms, no./100ml.; Station 1. Prethermal Period. 118
60. Fecal Coliforms, no./100ml.; Station 1. Thermal Period. 119
61. Fecal Coliforms, no./100ml.; Station 3. Prethermal Period. 120
62. Fecal Coliforms, no./100ml.; Station 3. Thermal Period. 121
63. Fecal Coliforms, no./100ml.; Stations 7 & B. Prethermal Period. 122
64. Fecal Coliforms, no./100ml,; Station B. Thermal Period. 123
65. Enterococci, no./100ml.; Station 1. Prethermal Period. 124
66. Enterococci, no./100ml.; Station 1. Thermal Period. 125
67. Enterococci, no./100ml.; Station 3. Prethermal Period. 126
68. Enterococci, no./100ml.; Station 3. Thermal Period. 127
69. Enterococci, no./100ml.; Stations 7 & B. Prethermal Period. 128
70. Enterococci, no./100ml.; Station B. Thermal Period. 129
71. Total Count Isolates, All Stations by Season. 1965-1969. 133
72. Total Count Isolates; Station 1. Prethermal Period. 134
73. Total Count Isolates; Station 1. Thermal Period. 135
74. Total Count Isolates; Station 3T. Prethermal Period. 136
75. Total Count Isolates; Station 3T. Thermal Period. 137
76. Total Count Isolates; Station 3B. Prethermal Period. 138
77. Total Count Isolates; Station 3B. Thermal Period. 139
78. Total Count Isolates; Station 6. Prethermal Period. 140
79. Total Count Isolates; Station 6. Thermal Period. 141
80. Total Count Isolates; Stations 7 & B. Prethermal Period. 142
81. Total Count Isolates; Station B. Thermal Period. 143

LIST OF TABLES

Page

1. Data sheet, Connecticut Yankee Atomic Power Plant, East Haddam, Connecticut. 3

2. Water quality standards for coastal waters; State of Connecticut. 12

3. Total Phytoplankton (10^3 cells/ml). 64

4. Comparison of correlation coefficient (r) and means ($\overline{X}$) of six parameters during thermal conditions. 67

5. Phytoplankton species collected by tows during thermal conditions. 72

6. Quantitative analysis of phyco-periphyton experimental data during the period July-October 1968. 77

7. Analysis of phytoplankton using the Jaccard Coefficient of Community (C.C.) and the Koch Index of Biotal Dispersity (I.B.D.). 80

8. Analysis of physo-periphyton using the Jaccard Coefficient of Community (C.C.) and the Koch Index of Biotal Dispersity (I.B.D.). 81

9. Habitat and Biochemical Activities of the Most Commonly-Isolated Bacteria from the Connecticut River. 131

10. Bacteria isolated at all stations during prethermal and thermal periods. 132.

11. Percentage distribution of bacterial groups at Station 3 (outfall area). 145

12. IMViC characteristics of total and fecal coliform plate isolates. 152

ACKNOWLEDGEMENTS

We are indebted deeply to the U.S. Dept. of the Interior, FWPCA, for their foresight in making funds available for this study. In particular, Mr. James Lamble and Mr. Joseph De Colla of the New England Basins Office and Mr. Kenneth Mackenthun were most helpful in providing administrative help and technical suggestions.

Special thanks are extended to Mr. Daniel Hedden of the Northeast Utilities Service Co. for his cooperation in supplying data on the operational characteristics and schedule of the CYAPC plant and for his general courtesy in making various portions of this study easier. Dr. Daniel Merriman, Director, The Connecticut River Investigation (Essex Marine Laboratory), was most gracious in keeping us informed on their progress and allowing us to summarize their conclusions.

The following individuals provided continuous interest and expertise in various portions of the study: Julia S. Rankin (Bacteriology), Delphine Kirby (Chemistry), John W. Foerster (Plankton and Chemistry), Dr. Francis Trainor and Wilber Widmer (Plankton) and Dr. John S. Rankin, Jr., (Benthic Invertebrates).

We acknowledge the able assistance of Christina M. Biela for her participation in field and laboratory analyses and data reduction.

Mr. Orem Campbell and the crew of the R/V UCONN provided shipboard support which made our field samplings consistent and efficient.

Special thanks are due Mr. Frank Friedman and the Goucher College (Maryland) Computer Center for their help in the computer routines.

Thanks are extended to Jessalyn O. Allen for patience and skill in secretarial assistance.

Finally, we are all indebted to Dr. John S. Rankin, Jr., Director, Marine Research Laboratory, for his encouragement during the entire study.

I. Introduction

A. Purpose of Study

A burgeoning population concentration coupled with an increase in overall affluence has been reflected perhaps most critically and dramatically in demands made upon the public utilities. In an attempt to employ the fruits of a highly technological society and to satisfy the doubling of electricity use every ten years, the large electric companies have countered by the interjection of a complex system of new power generating facilities, many of which include nuclear power sources. While these plants are capable of producing comparably greater amounts of electricity than from fossil fuel and eliminate the air pollution hazard of conventional plants, the scientific and lay communities have voiced considerable concern over a new potential environmental threat - thermal pollution (e.g., 1, 2).

Public Act 57, the Clean Water Act of Connecticut (3) defines "pollution" as "harmful thermal effects or the contamination or rendering unclean or impure of any waters of the state by reason of any wastes or other material discharged or deposited therein by any public or private sewer or otherwise so as directly or indirectly come in contact with any waters.....". Further, "harmful thermal effect" means "any significant change in the temperature of any waters resulting from a discharge therein, the magnitude of which temperature change does or is likely to render such waters harmful, detrimental or injurious to public health, safety or welfare, or to domestic, commercial, industrial, agricultural, recreational or other legitimate beneficial uses, or to livestock, wild animals, birds, fish or other aquatic life....".

In fact, "pollution" or harmful thermal effect may be an appropriate description of the effect of nuclear plant discharges; however, it does not seem reasonable to apply the term on an *a priori* basis. Since only twenty nuclear generating stations are operating currently in the U.S., there are therefore few definitive studies of a "before" and "after" nature on these sites. Moreover, what may be shown for a freshwater environment cannot necessarily be extrapolated to the marine environment. It is dubious that any study could encompass *all* the biota potentially affected or the significant allied physical-chemical parameters. Only through a series of comprehensive synoptic investigations on the concerned ecosystem can any rational results be obtained. It is hoped that studies are planned for at least some of the approximately sixty additional plants either on order or already under construction.

The literature provides some excellent bases for research in the form of reviews on thermal effects (4-10), bibliographies (11-15), specific comprehensive studies (16-19), summaries of work in progress (20-22), and symposia (23-25).

The overall objective of the present study was to develop fundamental data and information relating to the effect of discharges from the Connecticut Yankee Atomic Power Company (CYAPC) plant on the aquatic environment so as to permit a more scientific evaluation of the disposal process. Specifically, we sought to determine baseline populations of bacteria, phytoplankton and chemical conditions existent in an area of the Connecticut River prior to plant operation with which to compare similar observations following initiation of power generation.

the author

B. Characteristics of CYAPC plant.

Table I shows some selected characteristics of the plant in question and of the Connecticut River in the immediate vicinity of the plant. Fig. I indicates the average monthly operating levels of the plant during our study period. These data were supplied through the courtesy of the Connecticut Yankee Atomic Power Company.

TABLE I. Data sheet, Connecticut Yankee Atomic Power Plant, East Haddam, Conn.

Plant Characteristics:

Reactor	Pressurized, Water Cooled & Moderated
Reactor Thermal Output	1825 Mwt
Electrical Generation, Gross	590 Mwe
Electrical Generation, Net, Approx.	562 Mwe
Full load Heat Rejection Rate	4.13×10^9 BTU/HR
Fuel	Slightly Enriched UO_2
Cooling Water Flow	830 CFS
Service Water Flow	53 CFS
Discharge Canal	
Total Flow in Canal	883 CFS
Length	6,000 Ft.
Width (surface)	60 ft.
Width (bottom)	40 ft.
Depth	10 ft.
Velocity	1 FPS (approx.)
Width at Discharge	600 ft.
Depth at Discharge	6 ft. (approx.)
Temperature Increase Through Plant	22.8°F Maximum

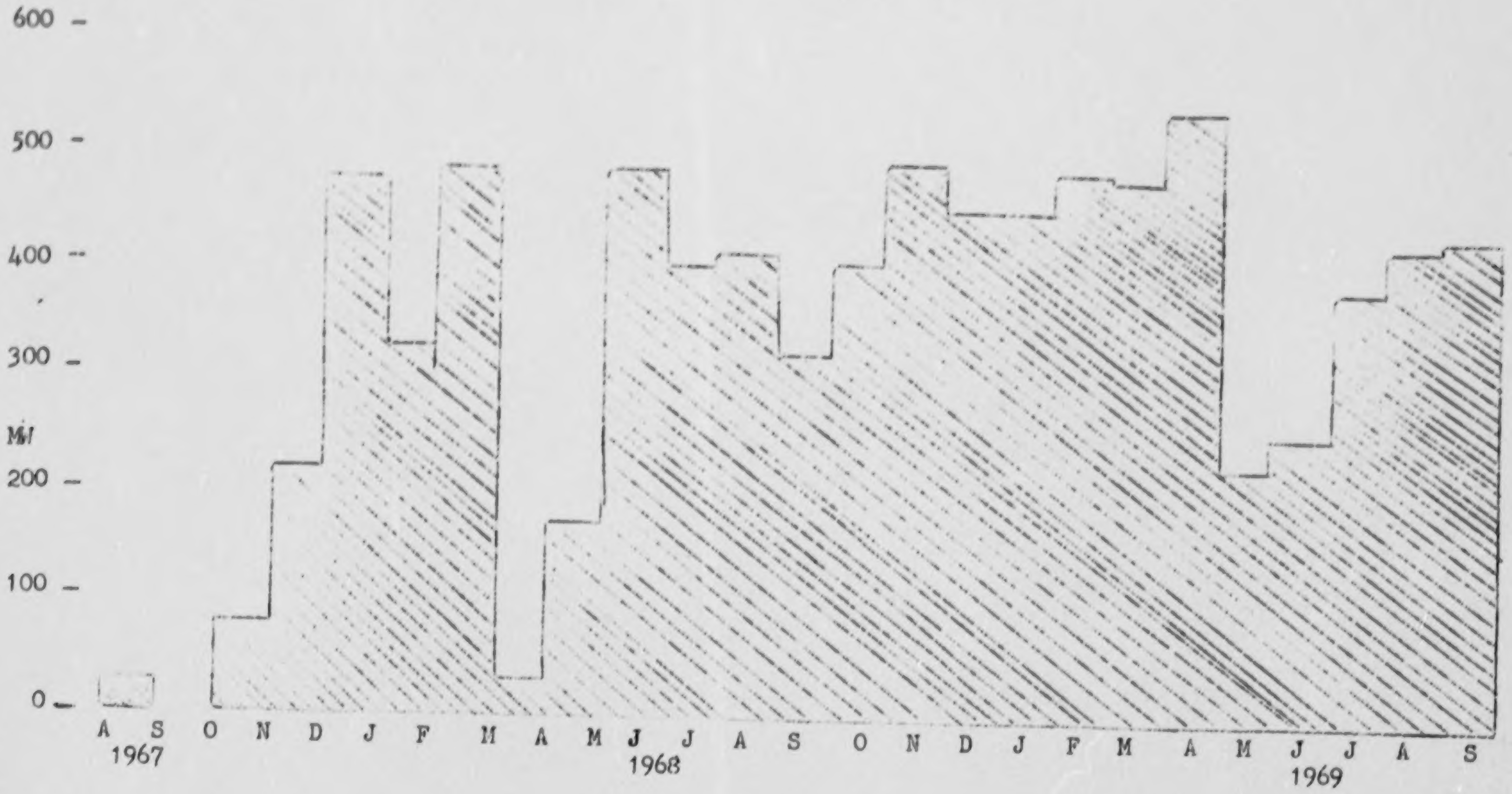
River Characteristics In The Vicinity Of The Plant:

Navigation Channel	Close to West Bank
Location	Across the River From Discharge Canal
Width	Variable 60 ft. to 600 ft.
Depth	15 ft. to 30 ft.
Tidal Range	2.5 ft.
Daily Average Tidal Flow	15,000 CFS (Minimum)

Approximate Water Plume Limits:
(Upper 3 ft. water column)

Ebb Tide: Downstream to East Haddam Bridge
Flood Tide: Upstream to Haddam Island

Figure 1. Average gross monthly generating levels of the CYAPC plant; megawatts electric.



Reproduced from best available copy.

II. Conclusions

None of the chemical characteristics of the Connecticut River which we have examined through September of 1969 have shown any obvious alteration as a direct consequence of thermal discharge from the CYAPC plant. The range of readings was similar for all parameters during prethermal and thermal periods of study, except for dissolved oxygen, nitrate and phosphate levels which were uniformly somewhat higher at all stations after plant operation. In part, we tentatively attribute the higher oxygen readings to turbulence imparted to cooling water as it leaves the plant and increased inorganic nutrient levels to greater run-off and enrichment from upstream sources of sewage effluent. Since. D.O. levels in the Connecticut River in the study area are not routinely so low as to be considered limiting to the biota, the increase in oxygen content near the plant outfall cannot be expected to result in significant stimulation of existing or "new" populations. While phytoplankton populations have increased during the study period as a possible combined result of higher nitrate and phosphate levels and thermal addition and may contribute to high daytime D.O. values, they may also produce low D.O. levels in early morning hours which are critical for fish and other river life.

A more obvious effect of thermal effluent was shown in qualitative plankton studies. A distinct shift from diatoms to blue-green algae was noted in both free-floating and attached plankton in the mixing zone near the outfall. If these changes continue or intensify, an alteration in the basic aquatic food chain may occur in this area since blue-green algae are less beneficial than diatoms as a food source for herbivorous forms. A potential ultimate loss in trophic level efficiencies and diminished food stocks for fish is thus possible.

Some changes in benthic invertebrate populations were observed also. Although the river bottom is a less continuous enviornment than the water column and our samples were not extensive, we can state that the results may indicate certain trends in population dynamics as a function of sediment temperature.

Some changes were noted in groups of microorganisms studied. Quantitatively, bacterial counts did not show any distinct alteration at any station although there were both field and laboratory indications of generic shifts among dominant members of the river microflora in the outfall area. However, we cannot predict at this time that these changes, if real, will be ultimately detrimental to the natural mineralization activities occurring in the river near the plant.

While we cannot conclude that the thermal discharge from the CYAPC nuclear plant has grossly or significantly affected the general ecology of the Connecticut River as of this date, it may represent an environmental additive whose ultimate effect remains unknown. We emphasize that our studies following initiation of plant activity lasted only 21 months and therefore must be considered to be of a short term value.

We have no information of the effects of fluctuating plant activity on the parameters studied herein. It is likely that periods of low power output and subsequent decreases in effluent temperature will occur as a result of refueling, maintenance or other reasons. Resumption of full power output and rising discharge temperatures may stimulate changes not noted in our study.

We suggest that studies similar to the ones reported herein be made periodically in the future and last for at least one year.

III. Summary

A four year study was made of the effects of thermal discharge from the Connecticut Yankee Atomic Power Co. nuclear-powered electricity generating station at East Haddam, Conn. on the chemistry and microbiology of the adjacent waters of the Connecticut River at four stations. The investigation extended continuously over a 27 month prethermal baseline period and a 21 month period following initiation of plant activity.

Samples of river water, both top and bottom, and sediment samples were collected on a bi- or tri-weekly schedule. Routine chemical determinations included salinity, conductivity, pH, dissolved oxygen, nitrate, ortho and total phosphate, and ammonia and total nitrogen. Temperature readings provided characterization of the thermal plume under varing tidal effects.

None of the chemical parameters studied showed any variation as a function of plant activity, although dissolved oxygen, phosphate and nitrate levels were uniformily higher at all stations after the introduction of heated effluent. The latter nutrient changes may be ascribed to increased land run-off during the study period and sewage effluent added upriver.

Qualitative and quantitative evaluation was made of phytoplankton populations. Plankton tow samples and phyco-periphyton (attached algae) were examined also. A general increase in all groups of phytoplankton was noted over the four year period at all stations and probably reflected increased nitrate and phosphate levels and possibly thermal addition. A rise in algal counts may in turn account for the higher daytime dissolved oxygen levels noted above. While we have no long-term continuous oxygen records, it is likely that early morning summer values may be below 2 mg/L and thus approach a critical level for fish.

A noticeable shift in plankton populations from diatoms to blue-green algae was noted in the mixing area of thermal outfall in both the water column and on submerged slides. This alteration may ultimately affect food chains in the outfall canal or in the river near the outfall. We emphasize that these observations were confined generally to the zone of mixing of effluent and river waters; no uniform alterations were detected at upstream or downstream stations a mile away.

Macrobenthic invertebrates were collected at stations I, 3 and B and identified.

Counts of mesophilic (30° C), psychrophilic (5° C) and thermophilic (45 and/or 55° C) bacteria were made. In addition, the following types of bacteria were enumerated: proteolytic, amylolytic, lipolytic, anaerobes, acid and base producers, "marine" forms, total and fecal coliforms and fecal streptococci (enterococci). Laboratory aspects of the study included generic identification of dominant isolates from mesophile platings, temperature tolerance of psychrophilic and thermophilic isolates, salinity and oxygen response of marine bacteria and anaerobes, chemostat studies on river water and biochemical characteristics of pollution-indicating bacteria.

No quantitative differences were noted in any of groups of bacteria studied. Field and chemostat studies indicated that, in the mixing zone near the outfall area, some shifts in dominant genera may have occurred; the Achromobacter-Alcaligenes group increased while the Aeromonas-Vibrio complex decreased. Other less obvious trends are discussed. Considerable adaptability to temperature, salinity and oxygen was shown by "thermophilic", "psychrophilic", "marine" and "anaerobic" bacteria.

It is stressed that all post-operational observations were considered to be relatively short term ones. With these limitations in mind, we cannot state that any drastic changes have occurred at the present time in the overall ecology of the Connecticut River as a direct result of the addition of thermal effluent. It is suggested that future parallel studies in the same area be considered for a more valid assessment of the effects of thermal addition on this environment.

We view the Connecticut River as chemically and biologically dynamic and, as such, is exhibiting a natural increase in inorganic salts as a result of climatological effects and increased upriver sewage effluent. This has led to rising populations of phytoplankton with subsequent extremes of diurnal dissolved oxygen levels. At present, the CYAPC plant may have functioned in an additive way in stimulating phytoplankton by thermal addition in the general plant area of the river and more specifically in the immediate outfall area.

IV. The Connecticut River

A. General Description.

The Connecticut River forms in the mountains above Fourth Connecticut Lake near the Canadian border and flows some four hundred miles through a basin two hundred and eighty miles long and sixty miles wide in four States and one Canadian Province. During the study period 1965-1969, the monthly mean flow of the Connecticut ranged from a low of 5,000 cfs in 1965 to a maximum of about 22,000 cfs in 1969 (U.S. Geological Survey figures; estimates from several Connecticut stations). The approximate annual mean Connecticut River discharge into Long Island Sound was as follows in thousands of cubic feet per second: 1965, 10; 1966, 13; 1967, 19; 1968, 18; 1969, 24.

At East Haddam, Conn. in the vicinity of the CYAPC plant the River varies in width from approximately 300 yards to 700 yards. At mean low water the depth ranges up to 30 feet in the navigation channel which varies in width from 60 to 600 ft. as it alternates from one side of the River to the other. The tidal effect at East Haddam has about a 2 foot range and results from a pushing back of fresh water flow downriver rather than a salt wedge intrusion at this point.

B. Water Quality.

In 1965, Congress passed the Water Quality Improvement Act with the intention of enhancing the quality and value of our water resource and to establish a national policy for the prevention, control and abatement of pollution. Under the Act each state submitted proposed standards for water quality improvement to the Department of the Interior for review and approval. The water quality standards include three essentials. The first is a letter classification ranging from SA to SD of desired water use for each reach of the river which is classed as a coastal water. The second is criteria which are the limits of measurable chemical,physical and biological qualities of the water and which are associated with each letter classification of water use. For example, a letter classification of SB is suitable for swimming and excellent fishery and, as such, requires high quality water in terms of the chemical, physical and biological criteria that can be measured in the water. The third essential is an implementation plan. This provides a schedule of actions leading to the building of sewage treatment plants necessary to achieve desired water quality goals.

Water quality standards for the State of Connecticut were approved in April 1970 by the U.S. Secretary of the Interior. A summary of these standards is contained in Table 2. The Connecticut River in the area from Hurd State Park in East Hampton to the mouth at Saybrook Point, including the site of the CYAPC Plant at East Haddam, is classified SB, although this area does not presently meet the appropriate standards. Water use under this classification is suitable for bathing and other recreational purposes, industrial cooling, shellfish harvesting for human consumption after depuration, excellent fish and wildlife habitat and good aesthetic value. Dissolved oxygen under this classification requires a minimum of 5 mg/l at all times. No temperature increases are allowed for SB as well as all other classifications for Connecticut coastal waters except where the increase will not exceed the recommended limit on the most sensitive receiving water use, and in no case exceed 85°F or in any case raise the normal temperature of the receiving water more than 4°F. Other applicable criteria are covered in Table 2.

C. Water Uses of the Connecticut River

1. Recreational Uses

Existing Federal and State outdoor recreation developments within the Connecticut River Valley area consist of 34 State parks, 19 State forests, 27 fish and game lands units, 38 boat access sites and a National Historic

TABLE 2. Water quality standards for coastal waters; State of Connecticut

CLASS	USE	DISSOLVED OXYGEN	SLUDGE DEPOSITS	COLOR & TURBIDITY	TASTE & ODOR
SA	Suitable for all sea water uses, including shellfish harvesting for direct human consumption (approved shellfish areas), bathing, and other water contact sports.	Not less than 6.0 mg/l at any time	None allowable	None in such concentrations that will impair any usages specifically assigned to this class.	Odor--none allowable.
SB	Suitable for bathing, other recreational purposes, industrial cooling and shellfish harvesting for human consumption after depuration; excellent fish and wildlife habitat; good aesthetic value.	Not less than 5.0 mg/l at any time.	None except that amount that may result from the discharge from a waste treatment facility providing appropriate treatment	Same as above	None in such concentrations that would impair any usages specifically assigned to this class & none that would cause taste & odor in edible fish or shellfish.
SC	Suitable for fish, shellfish & wildlife habitat; recreational boating, and industrial cooling; good aesthetic value.	Not less than 5 mg/l for more than 6 hours during any 24-hour period and at no time less than 4 mg/l.	Same as above	Same as above	Same as above
SD	Suitable for navigation, power and certain industrial cooling water; migration of fish; good aesthetic value.	Not less than 2 mg/l at any time	Same as above	Same as above	Same as above

TABLE 2. Continued

CLASS	pH	COLIFORMS PER 100 ml	ALLOWABLE TEMPERATURE INCREASE	CHEMICAL CONSTITUENTS
SA	6.8-8.5	Not to exceed a median MPN of 70 and not more than 10% of the samples shall ordinarily exceed an MPN of 230 for a 5-tube decimal dilution or 330 for a 3-tube decimal dilution.	None except where the increase will not exceed the recommended limit on the most sensitive receiving water use, and in no case exceed 85°F or in any case raise the normal temperature of the receiving water more than 4°F.	None in concentrations or combinations which would be harmful to human, animal or aquatic life or which would make the waters unsafe or unsuitable for fish or shellfish or their propagation, impair the palatability of same or impair the water for any other use.
SB	6.8-8.5	Not to exceed a median value of 700 and not more than 2300 in more than 10% of the samples.	Same as above	None in concentrations or combinations which would be harmful to human, animal or aquatic life or which would make the waters unsafe or unsuitable for fish or shellfish or their propagation or impair the water for any other usage assigned to this class.
SC	6.5-8.5	Not to exceed an average in any 30-day period of 5000 nor exceed this value in more than 20% of the samples collected during the period.	Same as above	Same as above
SD	6.5-8.5	None in such concentrations that would impair any usages specifically assigned to this calss.	Same as above	Same as Class SA

Site. Of these units, 60, with a total of some 22,000 acres, are on the Connecticut River. There are some 838 miles of river frontage of which only 79 miles (9%) are at present in public ownership. The 38 publicly-owned or operated boat access sites have an average size of one acre with extremely modest shore frontage. There are numberous informal access sites on public and private land. The majority of the boat launch sites are State-owned, but the public also has use of launching and docking facilities at 63 privately-owned liveries, marinas and boating clubs. Many private landings are maintained by individual riverfront property owners.

At present 57% of the river's length supports productive sport fisheries. An additional 35% is classed as marginal, with moderate levels of pollution, while the remaining 8% is essentially devoid of fish life.

Although the Atlantic salmon has disappeared and only a few striped bass are found other than at the mouth, the American shad has remained. At Enfield Dam, the best shad fishing area of the river, catches have gone as high as 16,000 in 1964.

Formerly the Connecticut River supported extensive populations in indigenous food and game fish as well as anadromous species like the Atlantic salmon, American shad and striped bass. Former shad and salmon runs were estimated in the millions. However, pollution and dams have eliminated or marginalized the fishery resource in about 50% of the entire river. The Atlantic salmon has disappeared and reduced runs of shad remain. Concern over the future fishery in the Connecticut has resulted in the establishment of a cooperative fishery restoration program among the Connecticut River Basin states, together with the U.S. Bureau of Sport Fisheries and Wildlife and the U.S. Bureau of Commercial Fisheries and includes active participation by the Univ. of Conn. Marine Research Laboratory. The objectives of this program are to obtain the full potential of the fishery resources of the River including both anadromous and resident species. The realization of this program will largely depend upon success of water quality improvement and maintenance programs throughout the Basin.

Swimming in the Connecticut River and tributaries has been severely restricted by pollution and other factors. Of the river's 36 major tributaries only 12 reach the main stem with a water quality level permitting water contact recreation. Camping and picnicking activities are restricted for similar reasons.

2. Commercial Fisheries

In addition to furnishing the most extensive sport fishery of the Connecticut River, the American shad provides the only significant commercial fishery. In 1965 approximately 352,000 pounds of shad were taken primarily from drifting gill nets at night in the lower river (from Middletown to Saybrook) at an estimated value of $74,000. Commercial interests from southern states have expressed interest recently in netting alewife and glut herring from the Connecticut River for reduction and/or fish bait purposes. The migratory runs of these species in Connecticut are later in the year than those in the south and could represent an extension of their commercial activities. The estuarine shell fishery of oysters, clams and blue crabs has virtually disappeared.

3. Commercial Navigation.

Although the U. S. Coast Guard considers the Connecticut River as navigable from its source to Long Island Sound, the vast majority of the river is passable only to canoes and other shallow-draft vessels. A 15 foot deep (minimum) channel is maintained from the Sound to Hartford to allow the passage of fuel tankers and barges. During the winter this channel is kept open by Coast Guard icebreakers since the major population centers on the river up to Hartford are dependent largely on the river shipping for replenishment of oil stores. An estimated 2,000,000 tons of cargo are transported annually.

4. Cooling Water and Waste Disposal.

The most heavily populated section of the Connecticut River basin includes the 62 miles from Hatfield, Massachusetts to Rocky Hill, Connecticut. Some data are available for this area (26). Several power plants in this area use large quantities of river water for cooling; two of these alone use about 317 MGD. The Pratt and Whitney Division of United Aircraft Corp. in East Hartford uses 720 MGD for cooling purposes.

Raw and partially treated sewage and industrial wastes cause excessive pollution in some areas of the river. The State of Connecticut Clean Water Act of 1967 provides the Water Resources Commission with authority to, among other things, adopt water quality standards, regulate existing pollution, prescribe corrective measures, file pollution abatement orders and make grants to communities and municipalities in a concerted effort to reduce waste disposal in the waters of the State.

5. Future Proposed Uses

In view of the brief summary above regarding use and abuse of the Connecticut River, Public Law 89-616, 89th Congress, S. 3510, 3 Oct. 1966, authorized the Secretary of the Interior to "study, investigate, and formulate recommendations on the feasibility and desirability of establishing all or parts of the Connecticut River Valley from its source to its mouth, in the States of Connecticut, Massachusetts, Vermont and New Hampshire, as a Connecticut River National Recreation Area." The Bureau of Outdoor Recreation provided this study (27) which is proposed as a "blueprint for long-range development of the vast recreation potential of the beautiful Connecticut River Valley, part of which is in the heart of the eastern megalopolis."

V. Logistics of Thermal Effluent Study

A. Description of Sampling Area.

Figure 2 shows the general location of the CYAPC plant relative to the surrounding area and the construction site of two nuclear power stations at Millstone Point, Waterford, Connecticut. Figure 3 is a detailed chart of the stations established near the CYAPC plant under study. Station 1 was approximately 100 yards upstream from the plant intake and about 200 feet off the east bank of the river. We anticipated that construction would hinder occupation of a station at the exact point of intake; thus, rather than change stations during construction, we chose Station 1 just above the intake. Station 3 was located at the junction of the effluent water with the Connecticut River. This outfall canal is closed at the surface by a string of large wooden floats. The navigation channel of the river at this point is on the west side of the river; the east side is very shallow. The depth of the outfall canal is only six to seven feet at its juncture point with the River and would not permit entry of our research vessel which draws seven feet of water. In addition, the immediate area of the outfall canal has shoaled considerably since plant operation (Fig. 4). Station 3 was established directly out in the river from the effluent canal and as close in to the wooden log boom as possible, usually 100-200 feet.

Initially, the plant was considering the possibility of discharging thermal effluent into the Salmon River and Station 7 was located there. Final plans did not include this arrangement and sampling at Station 7 was discontinued as of 27 September 1966. After this date Station B was established in the navigation channel just off blinker #38A on the east bank of the river, approximately 1.5 miles below Station 6, which was maintained just below the mouth of the Salmon River.

Figure 2. General location of CYAPC plant at East Haddam, Conn.

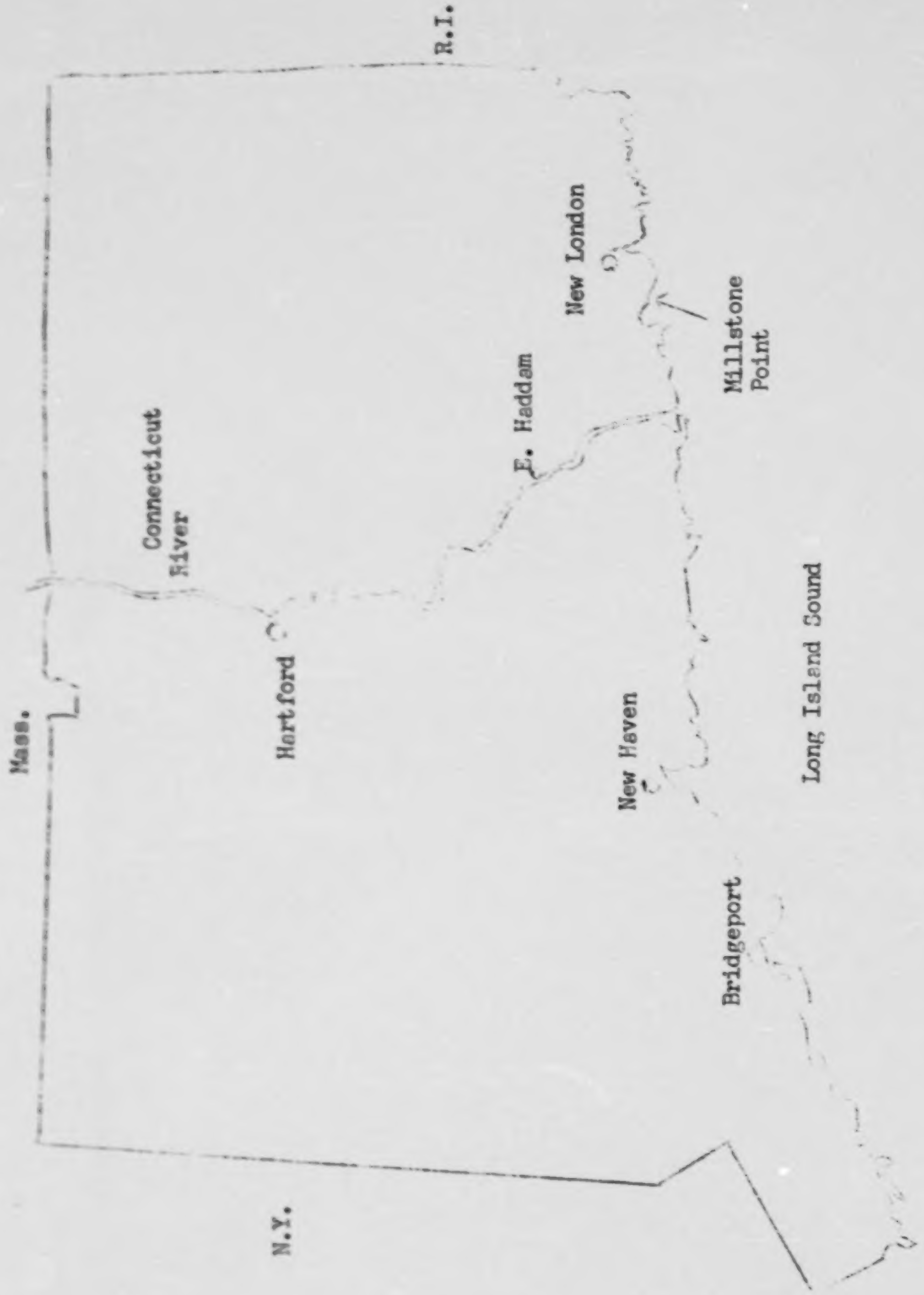

R.I.
New London
Millstone Point
E. Haddam
Connecticut River
Mass.
Hartford
New Haven
Long Island Sound
Bridgeport
N.Y.

Figure 3. Connecticut River Study Area.

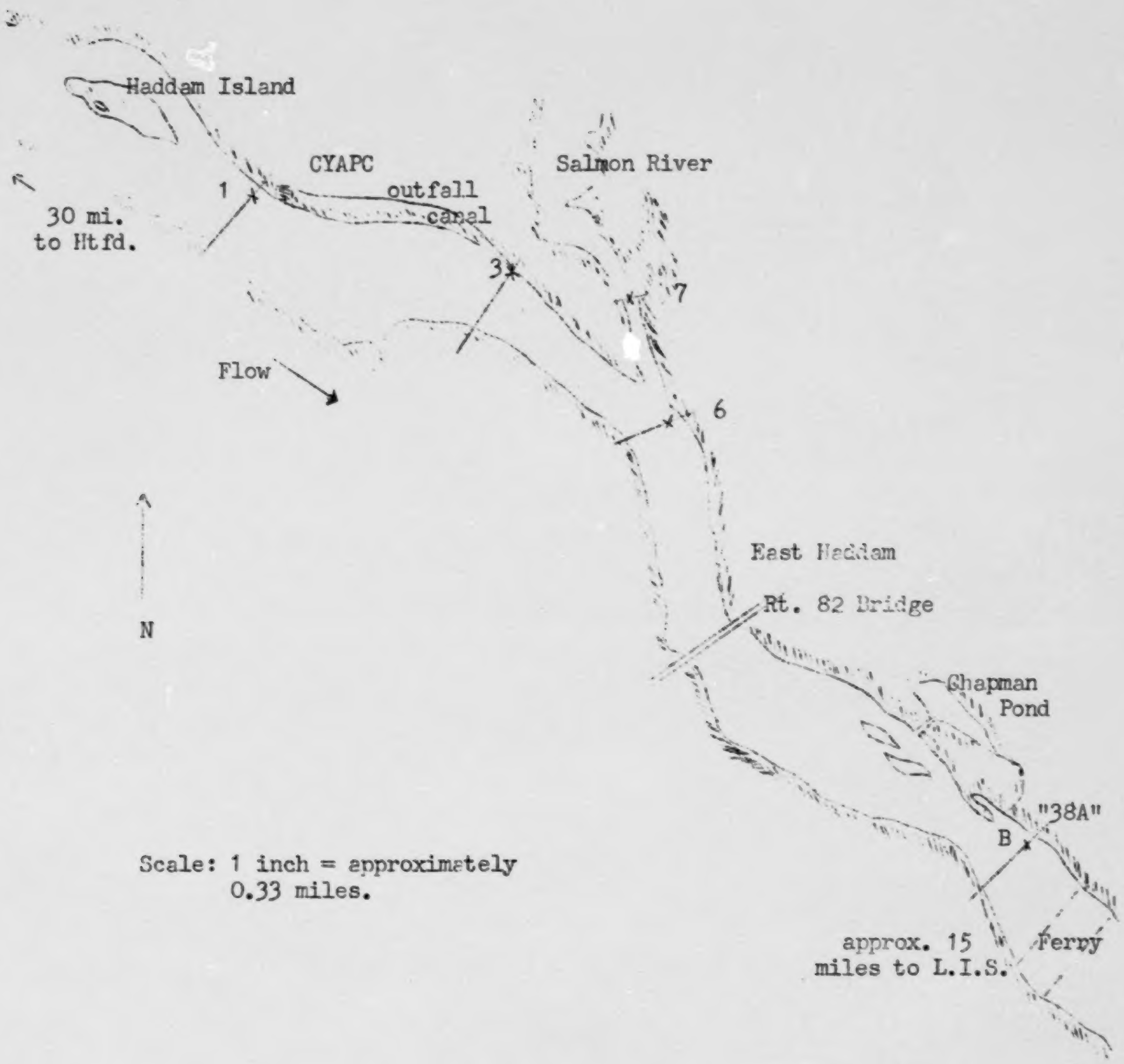
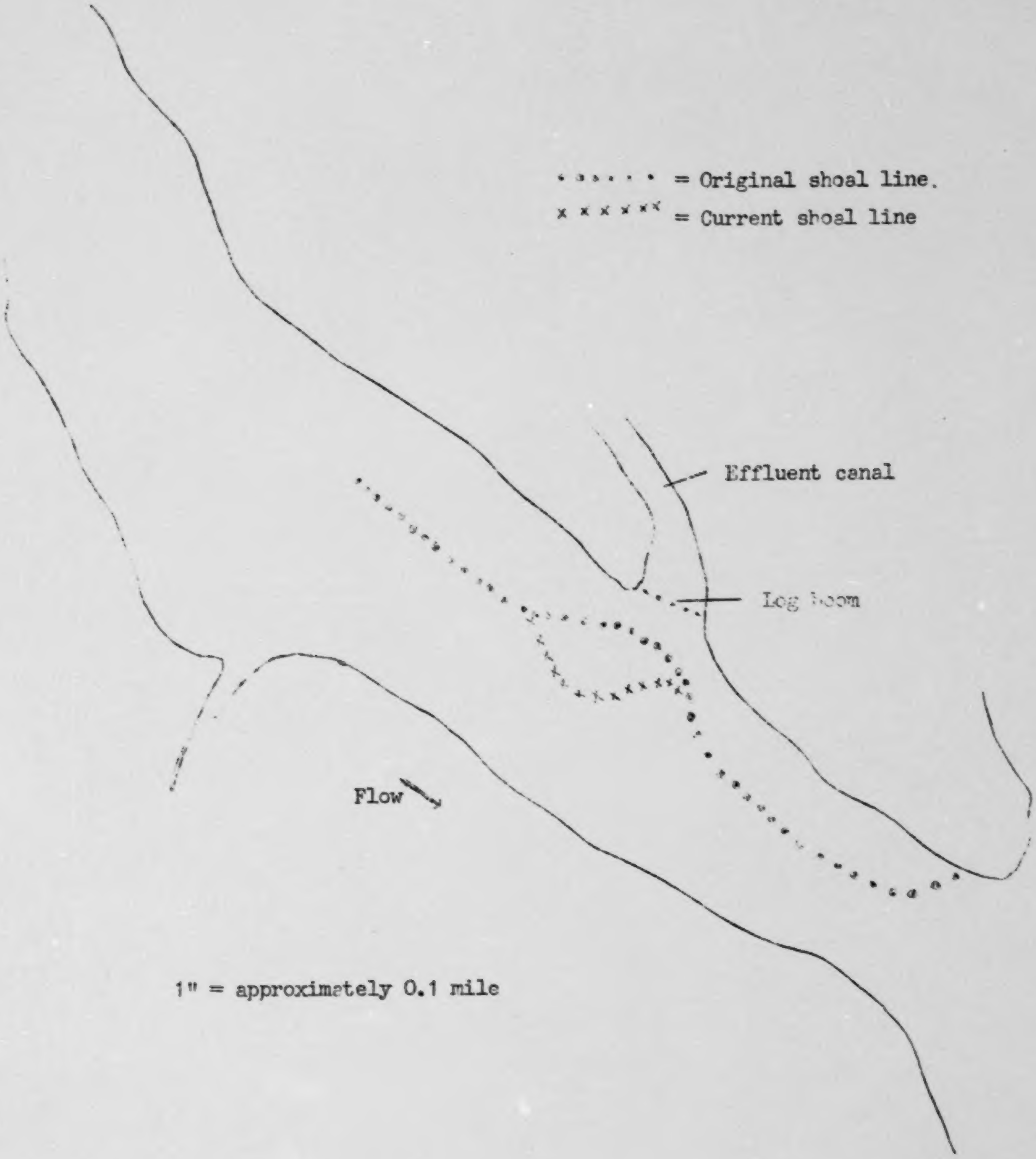

Haddam Island
CYAPC
outfall
canal
Salmon River
1
3
7
6
30 mi.
to Htfd.
Flow
N
East Haddam
Rt. 82 Bridge
Chapman
Pond
"38A"
B
Ferry
approx. 15
miles to L.I.S.
Scale: 1 inch = approximately
0.33 miles.

Figure 4. Approximate extent of shoaling at Station 3.


• • • • • • = Original shoal line.
x x x x xx = Current shoal line
Effluent canal
Log boom
Flow
1" = approximately 0.1 mile

Through the actions and recommendations of the groups mentioned above, the River can continue to be a multi-use resource. We envision the role of our thermal discharge study as providing basic data on the potential effects of modern technology on this resource.

B. Field Sampling

During the first year [illegible] our research samplings were made every 2 weeks; after this a tri-weekly schedule was maintained. These intervals were adhered to as much as possible. Occasional problems arose, particularly during the winter months when thick ice closed the river, even to barge traffic. If a trip could not be rescheduled within 2 days, it was postponed until the following week. Thus, while 4 week sampling intervals occurred occasionally, the next trip would be made in 2 weeks such that the total number of trips per contract period was maintained.

During three winter periods, solid ice in the river prevented any sampling by boat. In these cases, holes were cut in the ice near our stations or sampling was done from the river bank closest to the station.

On each trip "top" water samples were collected a few inches down from the surface in sterile glass bottles for bacteriological analysis and in Van Dorn (28) samplers for phytoplankton and chemical determinations. "Bottom" samples were collected approximately 1 foot off the river bed using Niskin samplers (29) for bacteriological testing and in Van Dorn bottles for other analyses. Bottom water samples in the Salmon River were collected using a specially designed apparatus and a sterile flask. Both glass bottles and Niskin bags were placed immediately in crushed ice until bacteriological examination in the laboratory, a period of time not exceeding 2 1/2 hours. For enumeration of anaerobic bacteria, approximately 25 ml of water sample was placed aseptically into sterile 1 oz prescription bottles containing a small amount of Bacto-Fluid Thioglycollate Medium. These bottles were loosely capped and placed in a desiccator which contained crystals of pyrogallol acid and 10% NaOH. The desiccator was evacuated using a pump, the above chemicals mixed to absorb residual oxygen and finally packed in crushed ice. During the early portion of the study anaerobic sulfate-reducing bacteria were enumerated aboard ship by serial dilution in tubes of Postgate's medium (30) which were overlaid with sterile paraffin and iced until incubation at 30° C in the laboratory.

Water for phytoplankton counts and identification were withdrawn from Van Dorn samplers into plastic bottles containing preservative (distilled water: 95% ethanol: formalin; 6:3:1 or merthiolate).

Salinity, conductivity and temperature were measured *in situ* using a Beckman model RS5-3 field salinometer. Samples for chemical analyses were withdrawn from Van Dorn Samplers into plastic bottles and iced until returned to the laboratory. Determinations of pH were made as soon as samples were collected using a battery-powered Photovolt model 85 pH meter. Dissolved oxygen was measured *in situ* with a Jarrell-Ash model 26-601 analyzer.

Bottom samples were collected using a Petersen grab. Temperatures at the center of the grab (a depth of 2-3 inches) were recorded. For bacteriological analysis the upper centimeter of the undisturbed samples was collected with a sterile spatula, transferred to small, sterile wide-mouth jars and iced until examined in the laboratory. The remaining grab sample was washed through a series of wire screens and macroinvertebrates collected, preserved in 10% formalin and subsequently identified.

C. Laboratory Procedures and Determinations.

1. Chemistry - although *in situ* dissolved oxygen values were recorded aboard ship, the azide modification (31) of the standard Winkler titration was used in addition. Ortho-phosphate (by the stannous chloride method) and

total phosphate were determined also according to Standard Methods (31). Nitrate (corrected for nitrite) values were obtained by recognized methods (32). Ammonia nitrogen and organic nitrogen were determined by the Kjeldahl distillation-titration procedure (31). Occasional chlorophyll measurements during a portion of the contract were made as outlined by UNESCO (33).

2. Phytoplankton - for quantitative and qualitative determinations, one liter volumes were concentrated by either sedimentation in graduated cylinders or continuous flow centrifugation. The Sedgewick-Rafter cell and Whipple disc technique with appropriate mathematical factors (31) were employed for counting and identification of algal cells. Some cultural experiments were performed during the first year of our study. Details of media and growth conditions can be found in an early report (34).

As discussed in previous resumes (35-37), we had only limited success in maintaining test panels for observation of attached phycoperiphyton. Some data were accumulated by the use of Foerster samplers (38) and scraping the wooden log boom at the entrance of the effluent channel.

Occasional 15 minute plankton tows were made at Stations 1, 3 and B using #20 mesh and 10 μ nanoplankton nets.

3. Bacteria - all plating procedures utilized the spread plate technique (39) to eliminate the effect of agar temperature on the development of various bacteria and to facilitate picking of colonies for additional laboratory characterization. Samples were diluted appropriately in buffered distilled water. All plates unless otherwise specified were incubated at 30° C.

Total counts of heterotrophic mesophilic bacteria were made on Bacto-Plate Count Agar (31) with 0.2% soluble starch. Duplicate plates were incubated for 48 hours. "Psychrophilic" bacteria were enumerated on Plate Count Agar with incubation at 5° C; plates were counted at 14 days. Counts of "thermophilic" bacteria were made as above with incubation at 45° C and/or 55° C and observed after two days.

Starch-hydrolyzing bacteria were enumerated on Plate Count Agar as above with added starch. After incubation for 48 hours, amylase activity was detected by flooding plates with iodine solution. A solid medium (40) incorporating powdered chromatographic grade cellulose was employed for observation of clear zones surrounding cellulose-hydrolyzing bacteria; incubation period was 2-3 weeks. A solid medium containing yeast extract, agar and unbleached chitin (Nutritional Biochemicals Co.) was used to enumerate chitin hydrolyzing colonies after 2-3 weeks incubation. Lipolytic bacteria were detected on spirit blue fat agar (41) after incubation for 6 days.

Proteolytic forms were counted on brom cresol purple milk agar and confirmed by flooding plates with 1 N HCl; incubation period was 48 hours. Acid - and base-producing colonies were recorded prior to acid treatment.

Although the salinity of the Connecticut River at the sampling stations was negligible, counts were made of bacteria capable of growth on a full strength sea water medium (Bacto-Marine Agar 2216E). Plates were incubated at 16°C and counted after 6 days. Upon return to the laboratory, appropriate spread-plate dilutions for anaerobes were made on Plate Count Agar with the plates incubated at 30° C in Weiss-Spaulding anaerobic jars or BBL GasPak anaerobe systems for 5-7 days.

Coliform determinations were made according to methods recommended by APHA, AWWA and WPCF (31) using the three tube most probable number (MPN) technique in lactose broth and the membrane filter technique using Bacto m-Endo Broth. Commencing 2 August 1966, both total and fecal coliform determinations on membrane filters were made according to Standard Methods and others (42) and MPN determinations were discontinued after 30 Sept. 1966.

Enterococci were detected similarly by the MPN method using Bacto-Azide Dextrose Broth. After 2 August 1966 fecal streptococci also were enumerated by the membrane filter technique with Bacto m-Enterococcus Agar (43). After the first year MPN determinations were discontinued, although they formed the basis for additional studies (44).

While numbers of bacteria, particularly maxima and minima, may reflect the influence of one or more physical or chemical parameters in a given environment; more specific studies on isolated cultures may provide additional relevant data for ecological studies. Toward this end, the following investigations were made.

From platings of heterotrophic mesophilic bacteria, predominant colonies were isolated routinely and subjected to a number of morphological and physiological determinations: patterns of flagellation (45), mode of carbohydrate fermentation (46), oxidase reaction (47) and other observations. Cultures were tentatively identified to genus by several procedures (48, 49).

A number of bacteria were isolated from "psychrophile" and "thermophile" platings and subsequently cultured on nutrient media at 5°, 25°, 30°, 35°, 45° and 55° C for more proper evaluation of temperature optima for growth.

Colonies were routinely picked from the sea water medium plates and transferred to slants of the same medium. After incubation at 16° C for 4 days, the cells were suspended in distilled water and inoculated into tubes of nutrient media prepared with both distilled water and full strength sea water and subsequently placed on a reciprocal shaker at 25° C. Growth was recorded after 48 hours.

All positive lactose broth cultures in the MPN series were confirmed as fecal coliforms by culture in Bacto-EC Medium at 44.5° C (50).

"Typical" coliform colonies have been picked routinely from membrane filter plates and examined morphologicallly and physiologically for coliform characteristics.

Positive tubes of Azide-Dextrose Broth (MPN) have been confirmed as fecal streptococci by culture in Bacto-Ethyl Violet Azide Broth. Colonies from membrane filter platings of enterococci were confirmed in both media.

Early counts of yeasts and molds on a medium (51) made selective by addition of chloromycetin were discontinued after the first year of study.

VI. Results: October 1965 - September 1969

A. Field Study

1. Physical characteristics at sampling stations

a. Shoaling - during our four year study a noticeable amount of shoaling occurred in the vicinity of the juncture of the effluent canal with the Connecticut River (Fig. 4). Since this area is on the opposite side of the River from the shipping channel the decreased depth poses no immediate danger to navigation. It did, however, affect sampling position as our vessel experienced considerable difficulty during the contract period in attaining consistent location at Station 3. At low tide, our position was an additional 50 feet further out from the mouth of the canal than at flood tide. These differences will be discussed below. U.S.C.& G.S. chart No. 266 shows this general area above the canal to be very shallow (1-2 feet) at mean low water.

b. Temperature Distribution - while our research was not designed specifically to delineate the thermal plume resulting from the discharge of heated effluent from the CYAPC plant, the general distribution of warm water was of obvious interest to us. During the winter ambient River temperature (Stations I and B) was 33-37° F, readings at the log boom were 50-55° F; during warmer months we recorded log boom temperatures as high as 100-102° F while Stations I and/or B values were approximately 85° F. At the log boom marking the entrance to the outfall canal the depth of the canal was 6-7 feet depending on the tide. At all times when temperatures were recorded at this point the water was isothermal from top to bottom at this point. This isothermal condition did not remain stable at any given time. Stratification occurred 50-100 feet out from the canal entrance; i.e., warmer water was confined to the upper layers (1-2 feet) of the River. As one proceeded outward from the canal the temperature change as a function of depth was very obvious. In one case, at a distance of 150 feet out the temperature fell from 92° F at the surface to 78° F at a depth of 6 feet.

In another instance, the surface reading at the bow of our vessel was 95° F at a distance of about 250 feet from the canal while at the stern (65 feet further away) the surface temperature was 81° F. Both values were confined to the upper 2 feet of water; below this the temperature dropped rapidly to ambient.

We should emphasize that temperature conditions varied considerably with tide condition. An earlier report (36) detailed some data on plume distribution. Other data (19) indicate that warmer water is pushed upriver by tidal effect and can be detected more than halfway across the River when all isotherms are plotted. Aerial thermographs (2, 19) confirm these observations. Under flood tide conditions these surface temperature differences can be seen by variations in ripple patterns and other physical characteristics; lines of floating detritus and debris, scum, etc. act as a "marker". Surface temperatures within 2 feet of each other and on either side of this line have varied from 97° F on one side to 79° F on the other. Again, these values were recorded only in the upper foot or so of water.

It is apparent that isothermal (top to bottom) heated effluent is confined to the immediate area of the log boom entrance to the outfall canal. In no case did we record vertical isotherms at a distance of more than 50-100 feet off this point. Beyond this, temperature variations do conform to general surface distributional patterns, but river levels and flows, tidal effects, eddies, etc. seem to have significant effects on these generalizations.

Figures 5 and 6 show top and bottom temperatures at Station 1 (located just above the plant intake) for both prethermal and thermal periods. These two sets of data are essentially alike and indicate that Connecticut River water at this point is isothermal and under no major influence from thermal effluent. It is possible that, under certain tidal conditions, some volume of effluent does reach the intake area and is recycled but we have no data to indicate that effluent water at more than 1-2° F above ambient reaches the intakes.

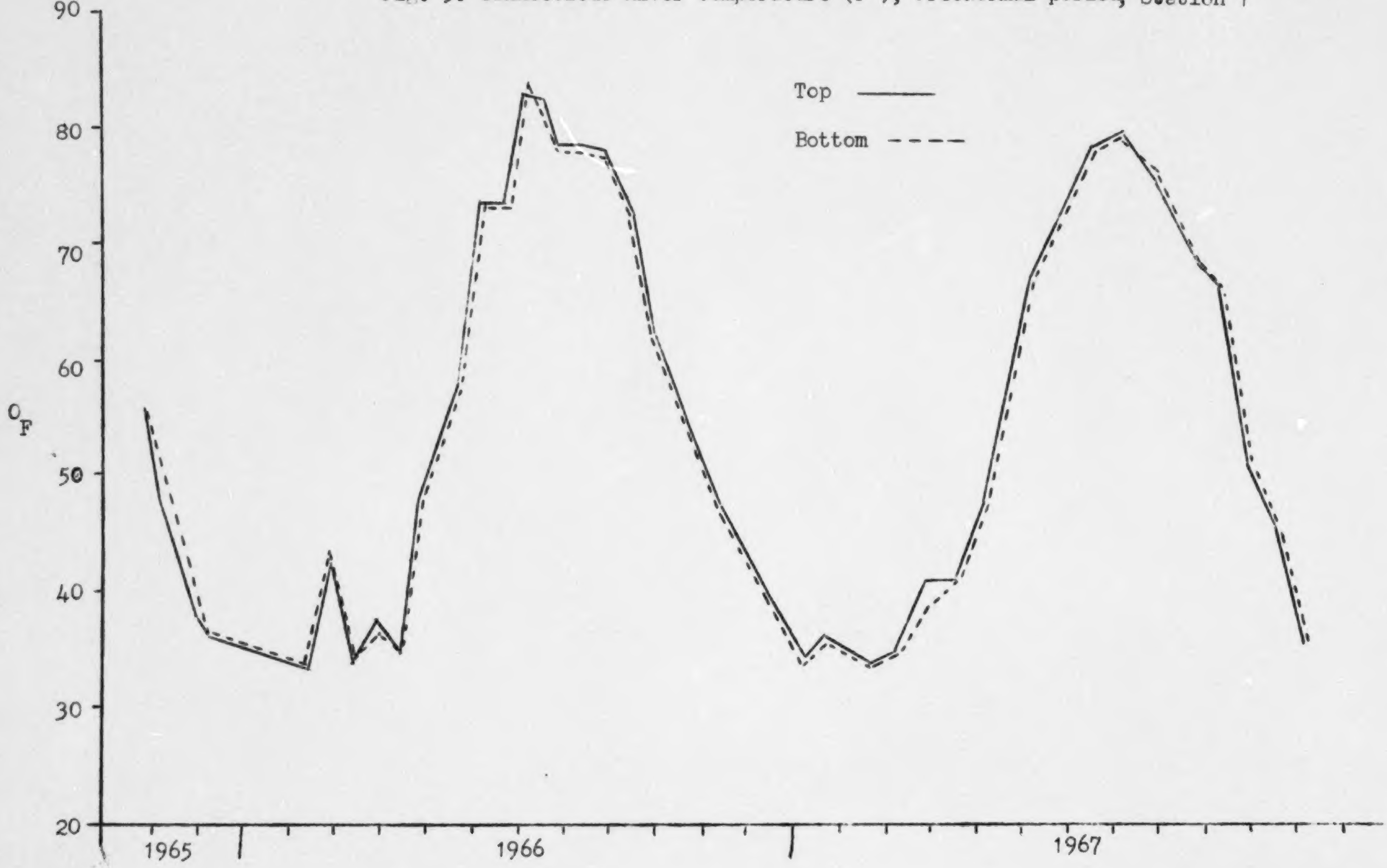
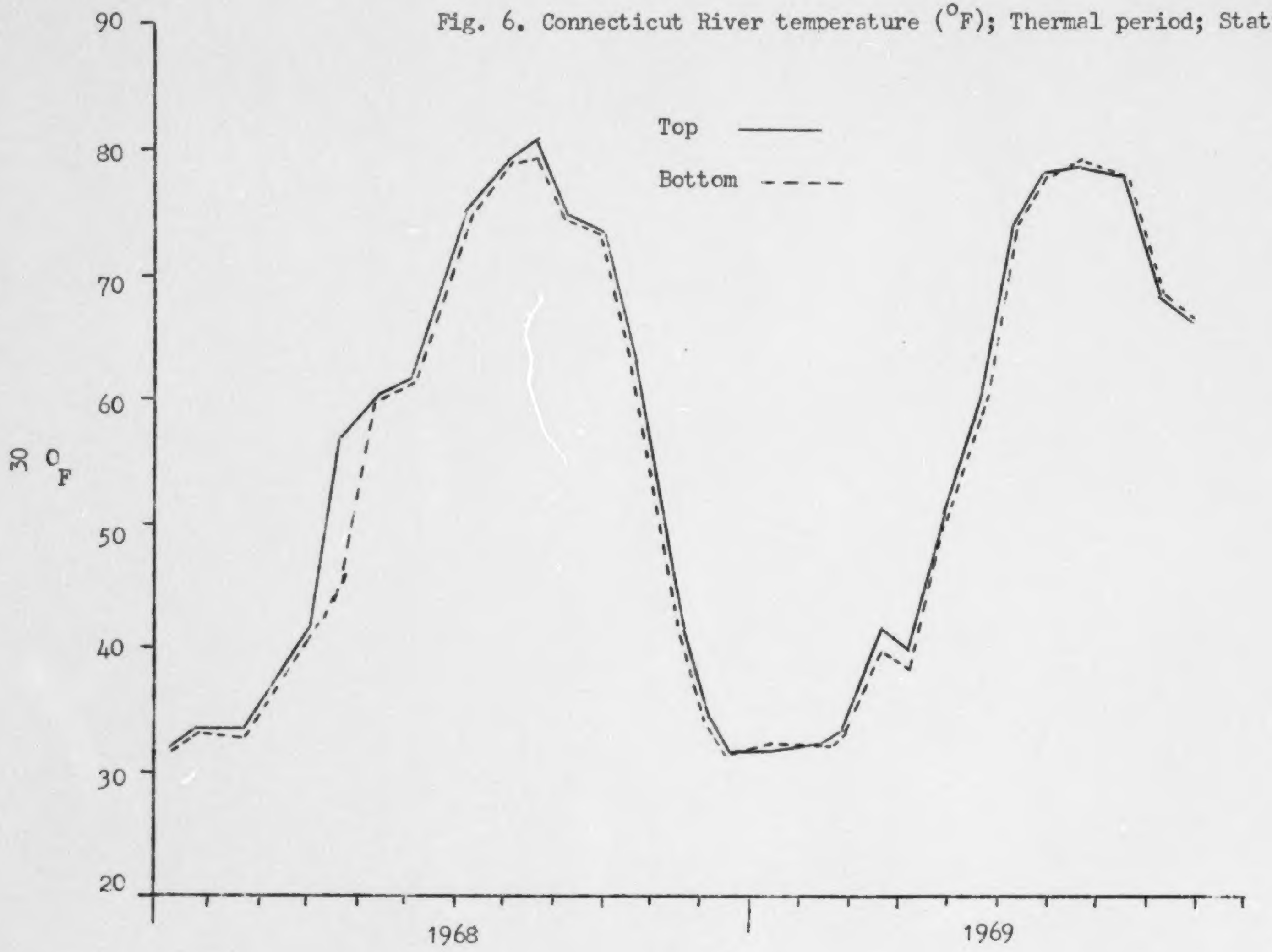


Fig. 5. Connecticut River temperature (F°); Prethermal period; Station 1

Fig. 6. Connecticut River temperature (°F); Thermal period; Station 1



Temperatures at Station 3 (off outfall) are shown in Figs. 7-8. Prethermal values mirror those at Station I while readings after initiation of plant operation are quite variable. As discussed above, readings taken at differing distances from the log boom entrance to the effluent canal and the tidal influence can be seen in the graph. Often, top and bottom temperatures were the same or varied by a few degrees. On one occasion the difference was approximately 20° F, which was the predicted rise in effluent as a result of cooling use. On this date the tide was high and the bow of the vessel was close enough to be in the area of maximum stratification. It should be noted that a temperature of 88° F was recorded once in the prethermal period. At Station 3 only the surface waters are affected by thermal effluent in the summer months since temperatures of bottom samples compare favorably with prethermal values. Winter temperatures of both top and bottom are higher.

Figures II and I2 show temperature readings at Stations 7 (partial prethermal) and 8. When compared with prethermal readings, thermal period observations at Station 6 (Figs. 9 and I0) do not reveal any effect of heated discharge. Station 7 was located in the Salmon River, a narrow and shallow tributary of the Connecticut River and therefore subject to greater ambient prethermal variation than Station 8. In both prethermal and thermal periods, however, there was no evidence of any effect of plant effluent.

2. Water Chemistry

a. pH. While normally a significant ecological parameter in confined or semienclosed aquatic environments, pH values in a moving, dynamic body of water would probably remain relatively stable unless influenced by the addition of large volumes of acidic or basic industrial wastes. The natural buffering action of a river can be ascribed to the presence of both organic and inorganic compounds and can be expected to accomodate inherent changes in pH as a result of phytoplankton activity, both photosynthesis and respiration,

Fig. 7. Connecticut River temperature (°F); Prethermal period; Station 3

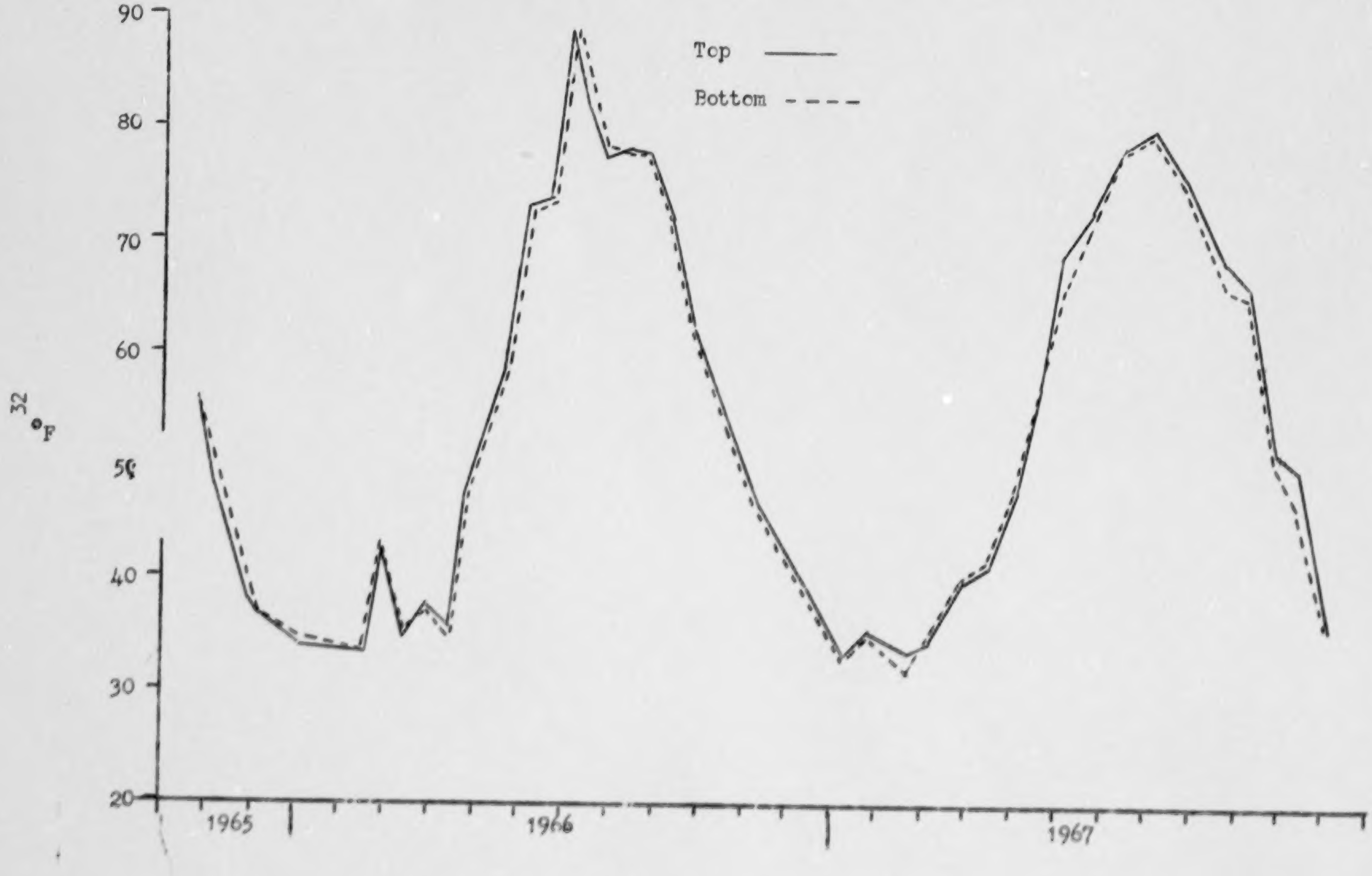


Fig. 8. Connecticut River temperature (°F); Thermal period; Station 3

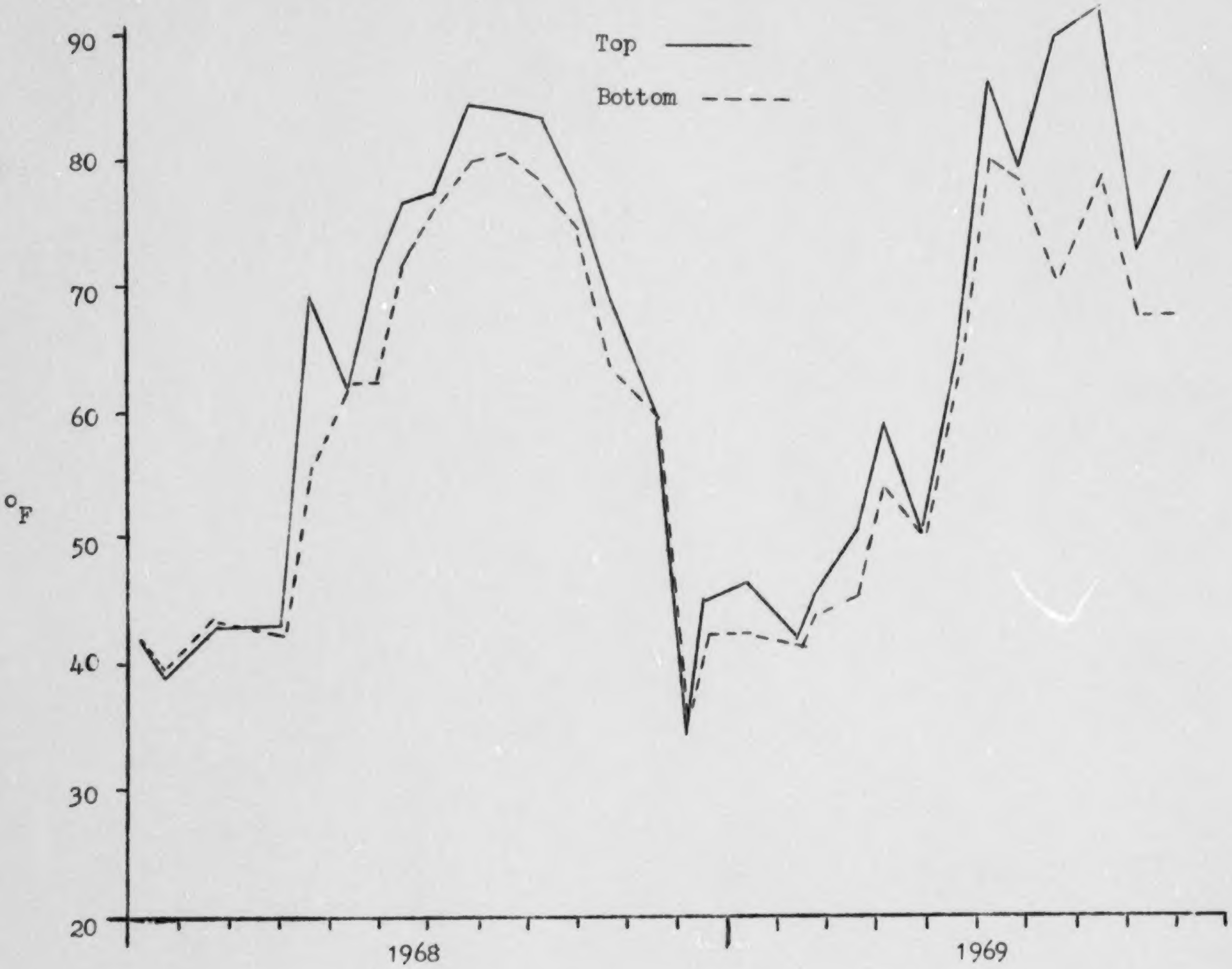


Fig. 9. Connecticut River temperature (°F); Prethermal period; Station 6

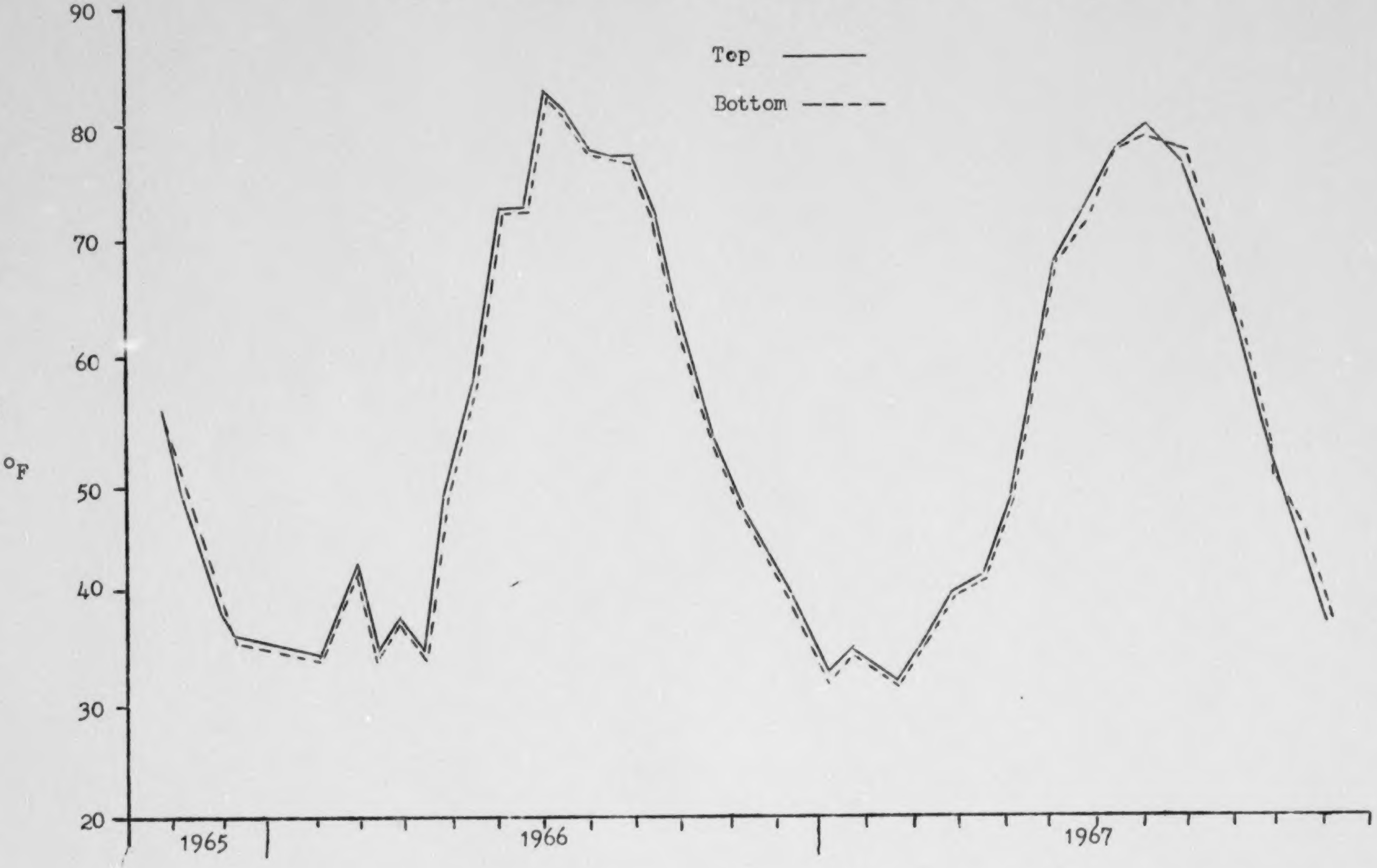


Fig. 10. Connecticut River temperature (°F); Thermal period; Station 6

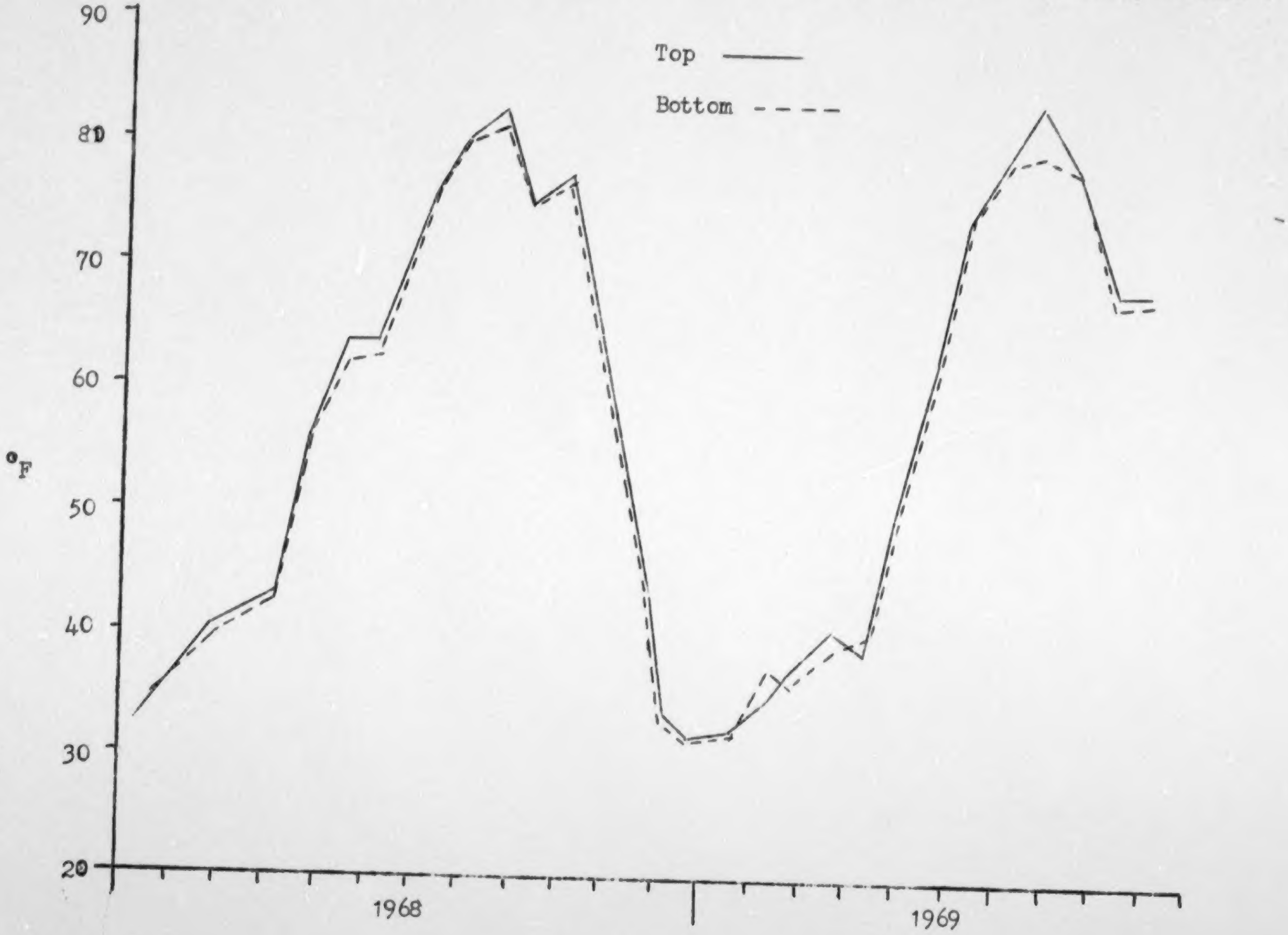


Fig. 11. Connecticut River temperature (°F); Prethermal period; Stations 7 & B

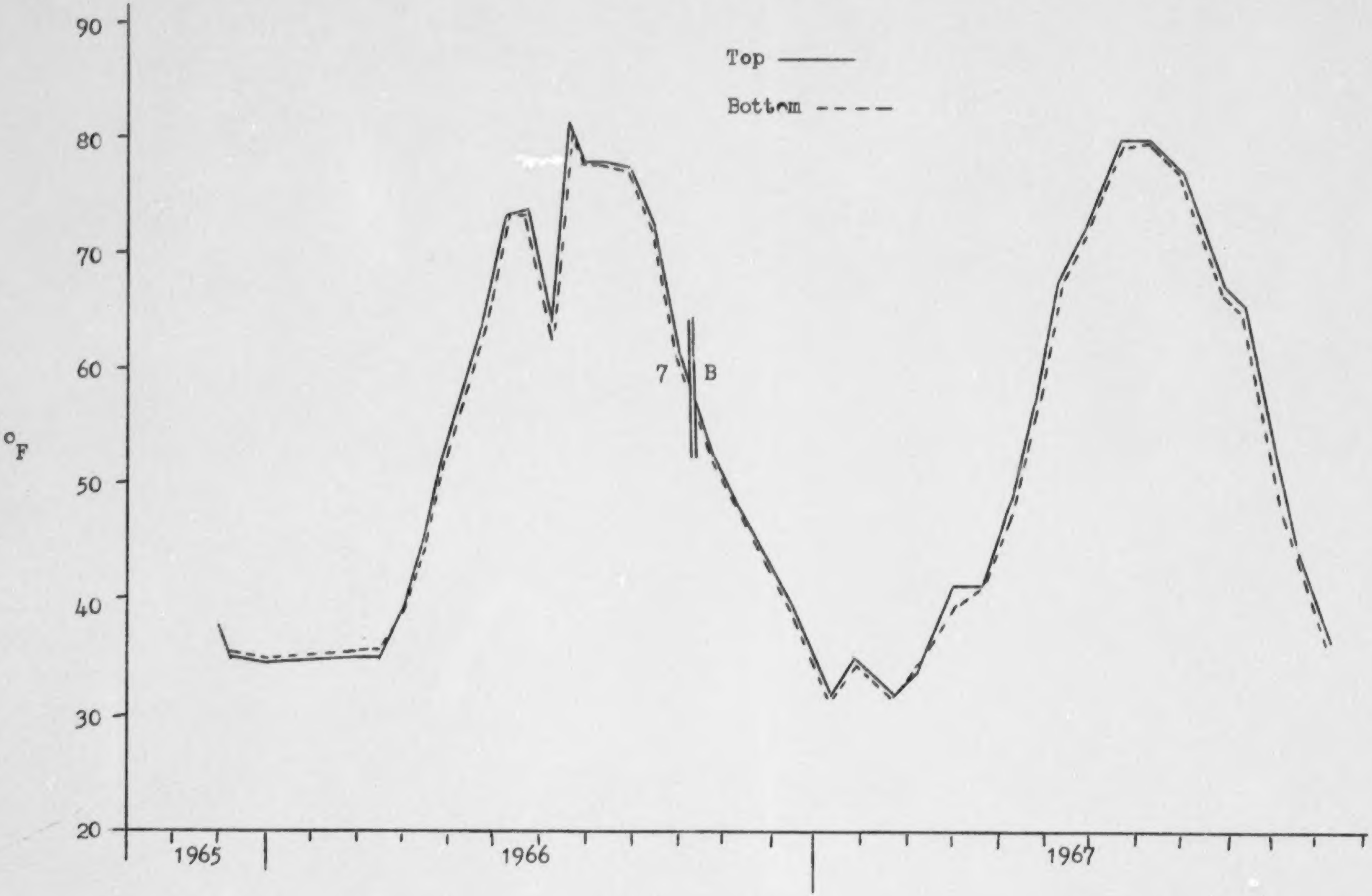


Fig. 12. Connecticut River temperature (° F); Thermal period; Station B

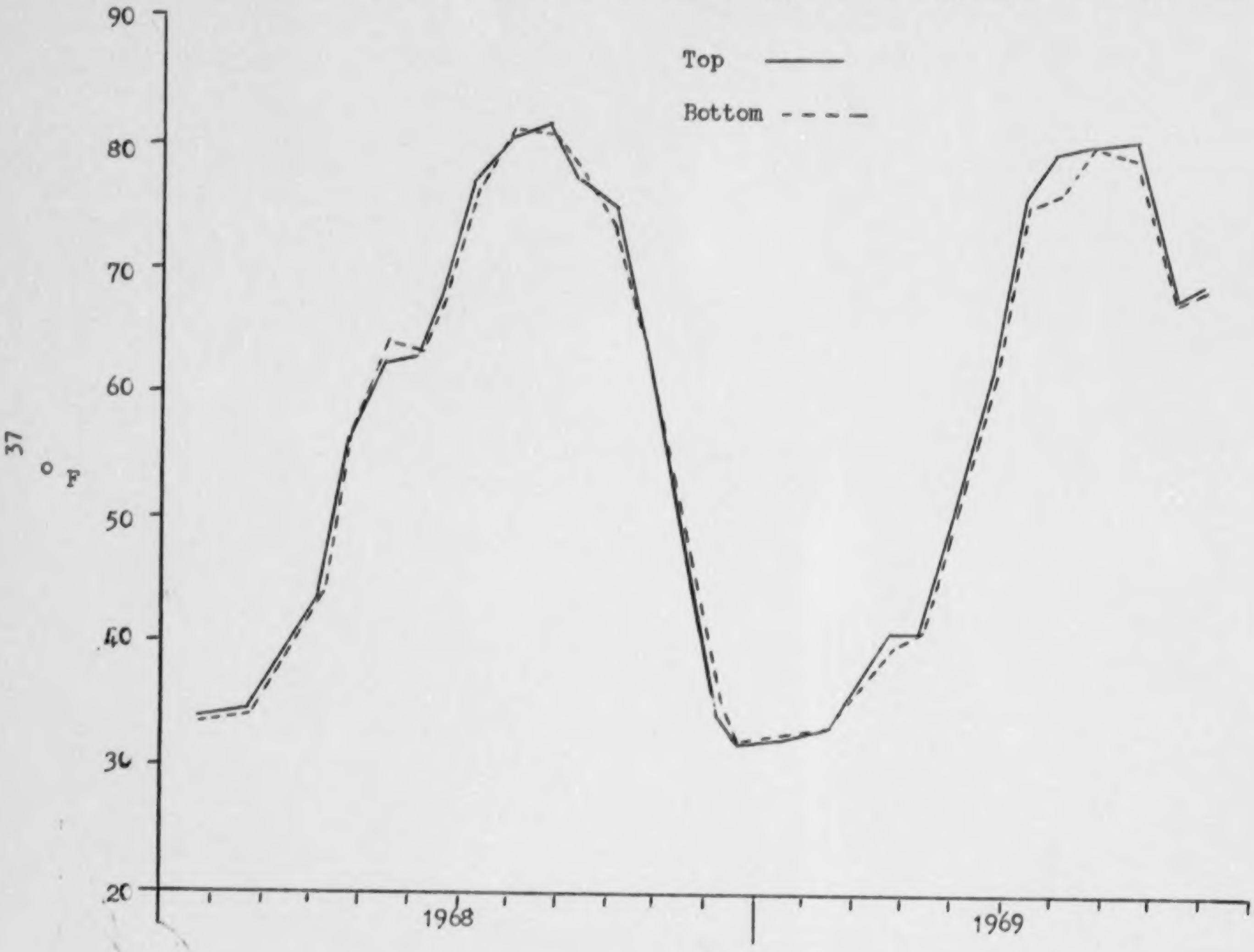
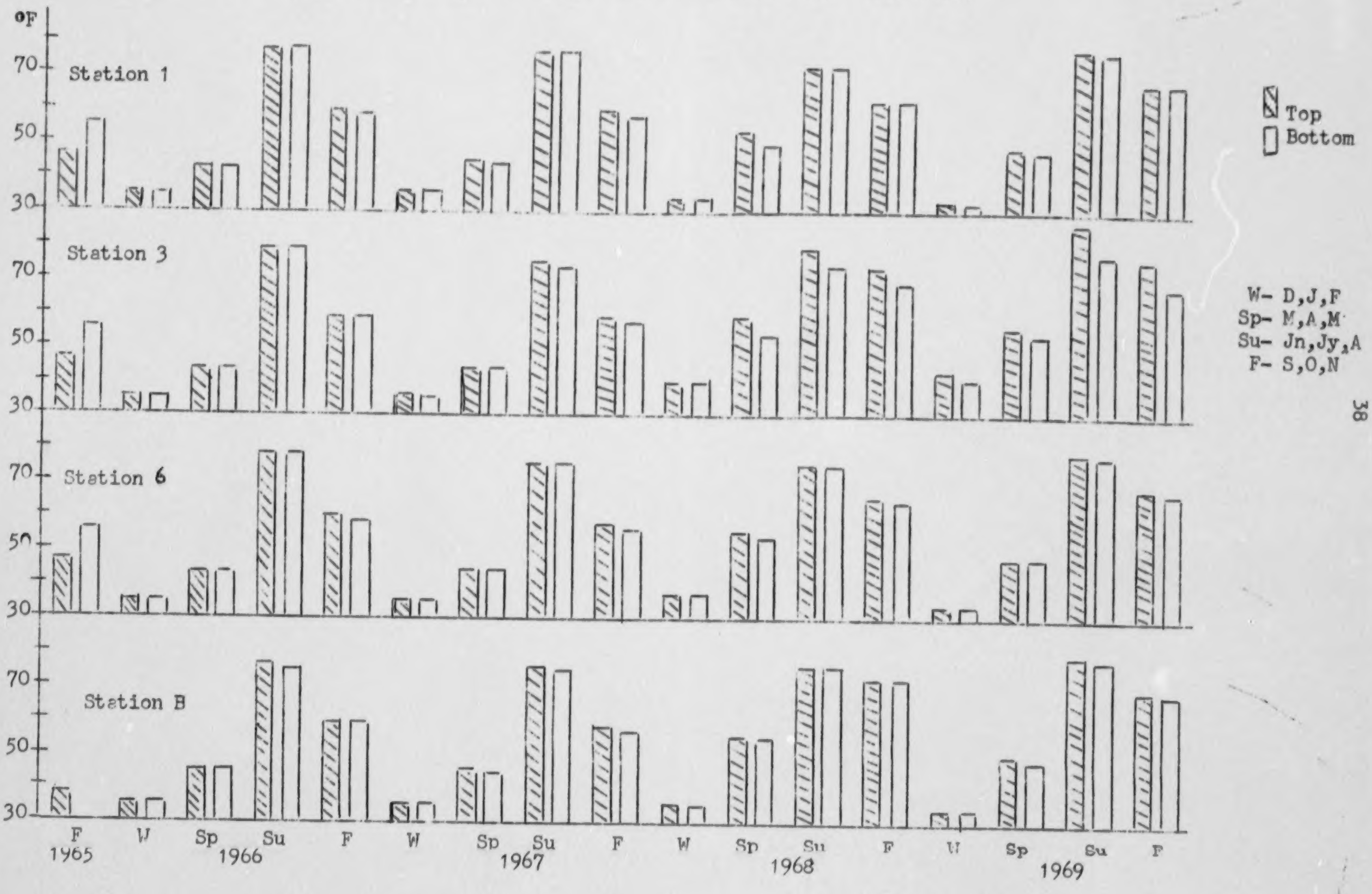


Figure 13. Average Seasonal Temperatures, Top and Bottom (OF). 1965-1969.



runoff, etc. Our studies have shown that the Connecticut River is essentially chemically homogeneous, and pH values follow this general continuity. Readings "before" plant operation ranged from 6.4 to 8.4 while "after" values were from 6.2 to 7.9. These values fall within pH limits of Class B-D waters as established by the New England Interstate Water Pollution Control Commission. The values are well within the limits of fish tolerance (52). However, the role of pH in an ecosystem may be in its effect on other environmental factors, especially the toxicity of various chemicals (e.g. ammonia) or the precipitation of materials. We have noted no uniform pH fluctuations at any station nor any correlation with increased effluent water temperature.

b. Salinity. The values were found to be extremely low during our entire study period; with one exception all readings were less than 2 parts per thousand and routinely less than 1 o/oo. In general, even dilute salt concentrations are not found above the East Haddam bridge (53) and thus salinity is not considered as a significant ecological parameter in the area of the power plant.

c. Dissolved Oxygen (D.O.). Figures 14-21 show dissolved oxygen values at all stations, top and bottom, for the entire study period. Comparison of all prethermal data clearly shows a general vertical and horizontal uniformity in D.O. Summer low readings of slightly over 2 ppm to winter highs of over 12 ppm were characteristic. While some minor variations occurred, all four graphs are essentially superimposable one on another; seasonal periods are obvious and clearly peaked.

All of our D.O. determinations were made between 1000 and 1300 hours and thus represent values which would approach daily maxima since photosynthesis masks respiration during daylight hours with a net production of oxygen. It is probable that summer early morning readings taken just before dawn would produce D.O. values below 2 ppm and thus at a critical level for some fish and perhaps other components of the ecosystem. The occasional minor fish kills

Figure 14. Connecticut River Dissolved Oxygen (ppm); Station 1. Prethermal Period.

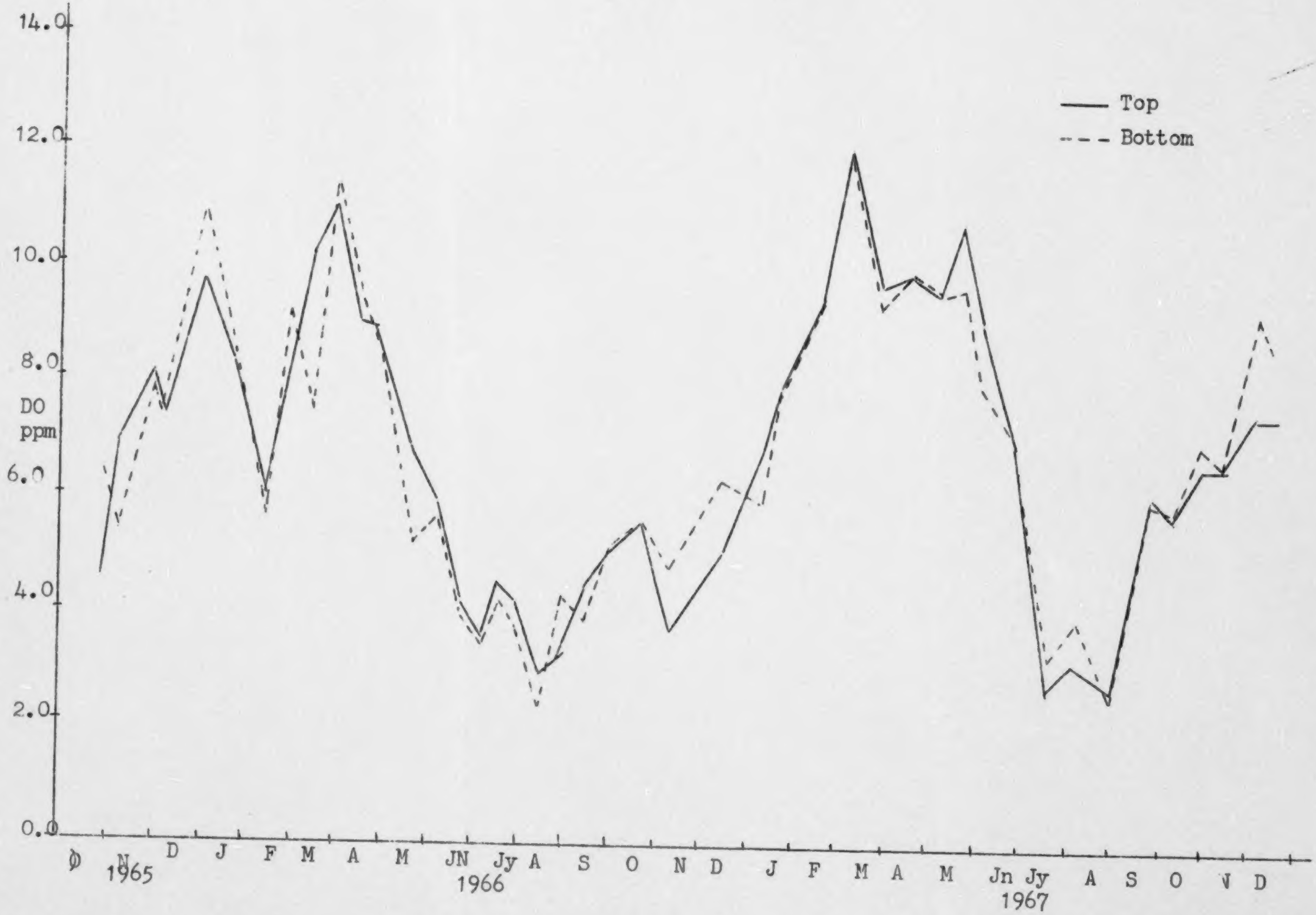


Figure 15. Connecticut River Dissolved Oxygen (ppm); Station 1. Thermal Period.

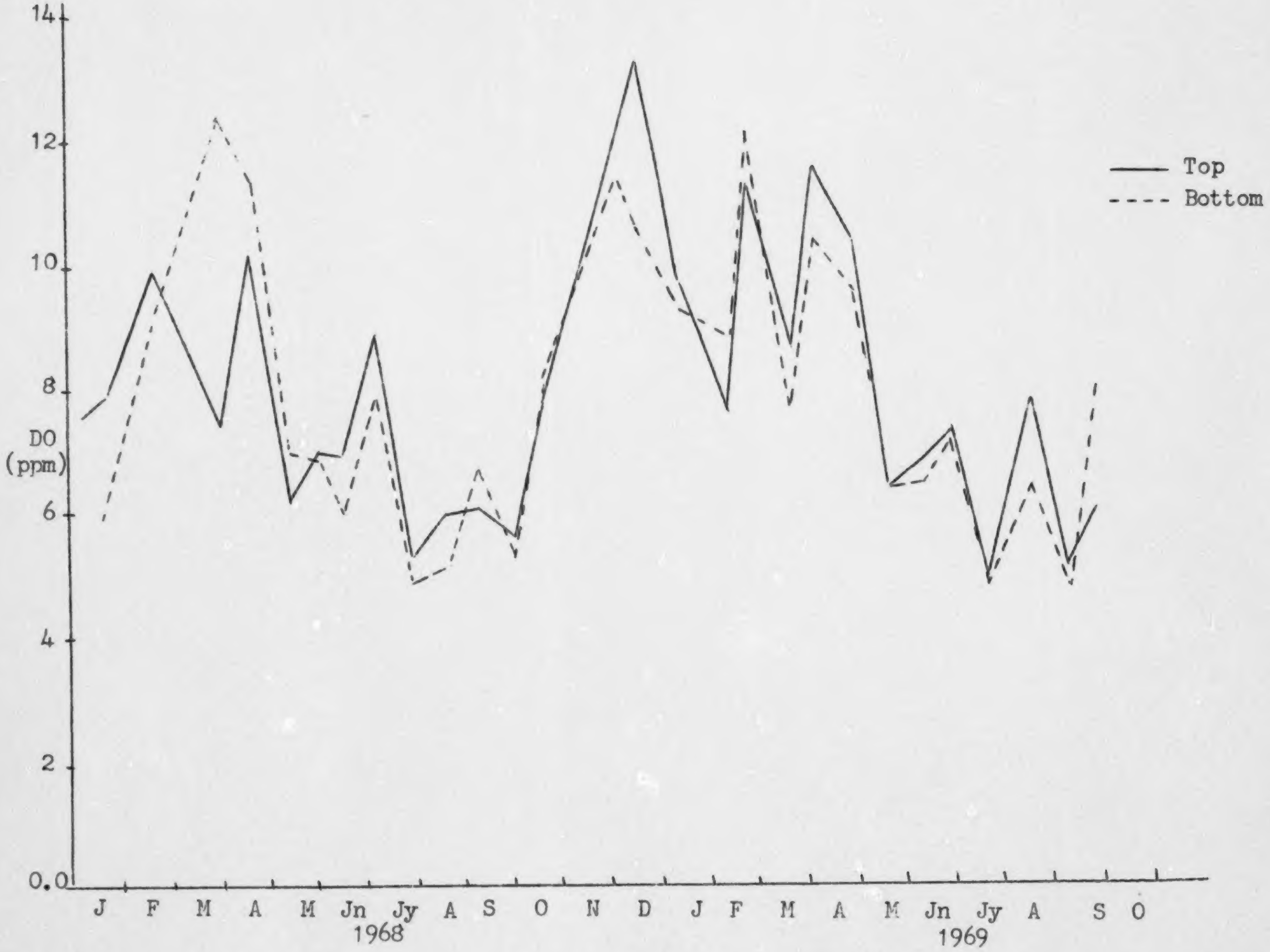


Figure 16. Connecticut River Dissolved Oxygen (ppm); Station 3. Prethermal Period.

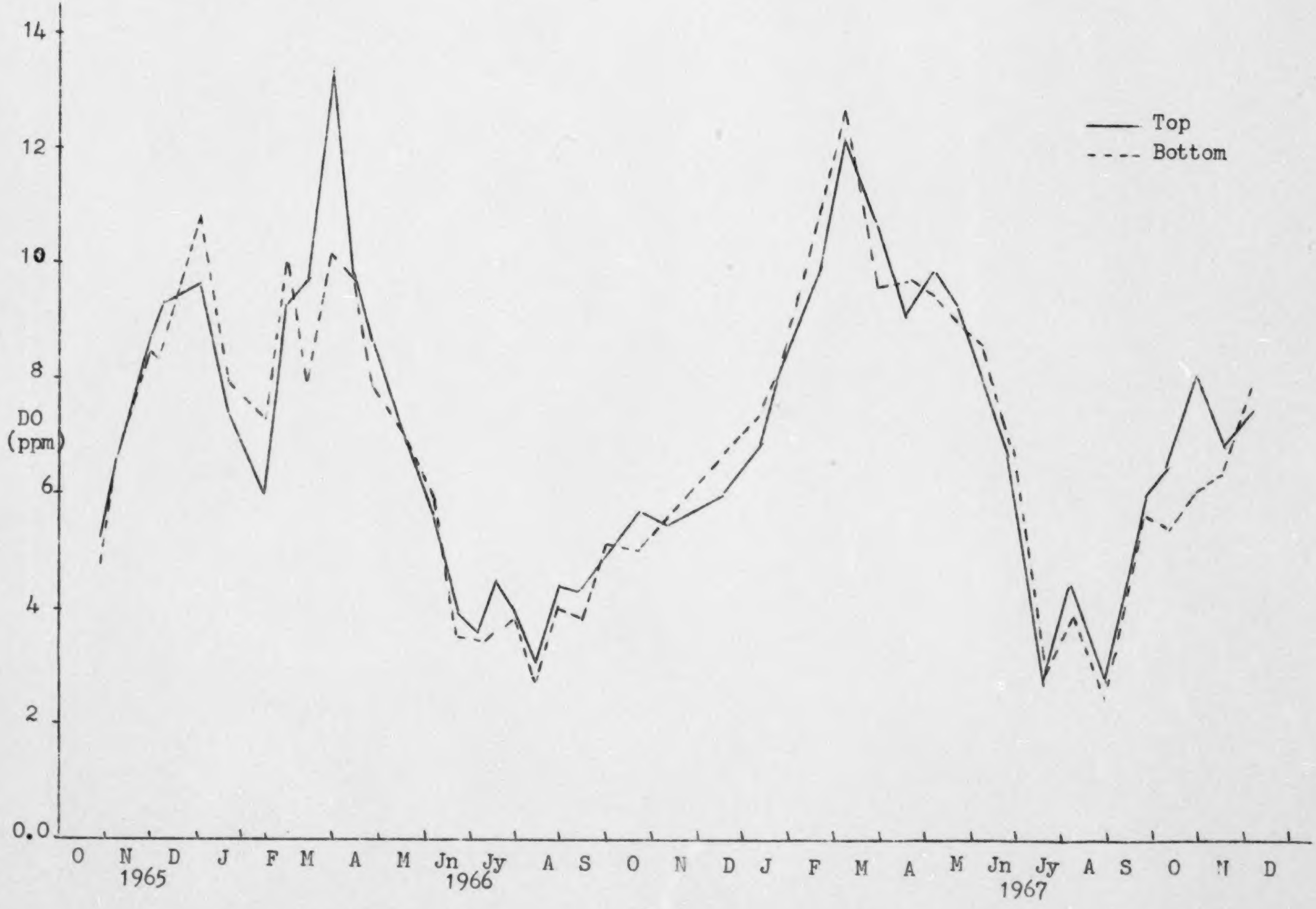


Figure 17. Connecticut River Dissolved Oxygen (ppm); Station 3. Thermal Period.

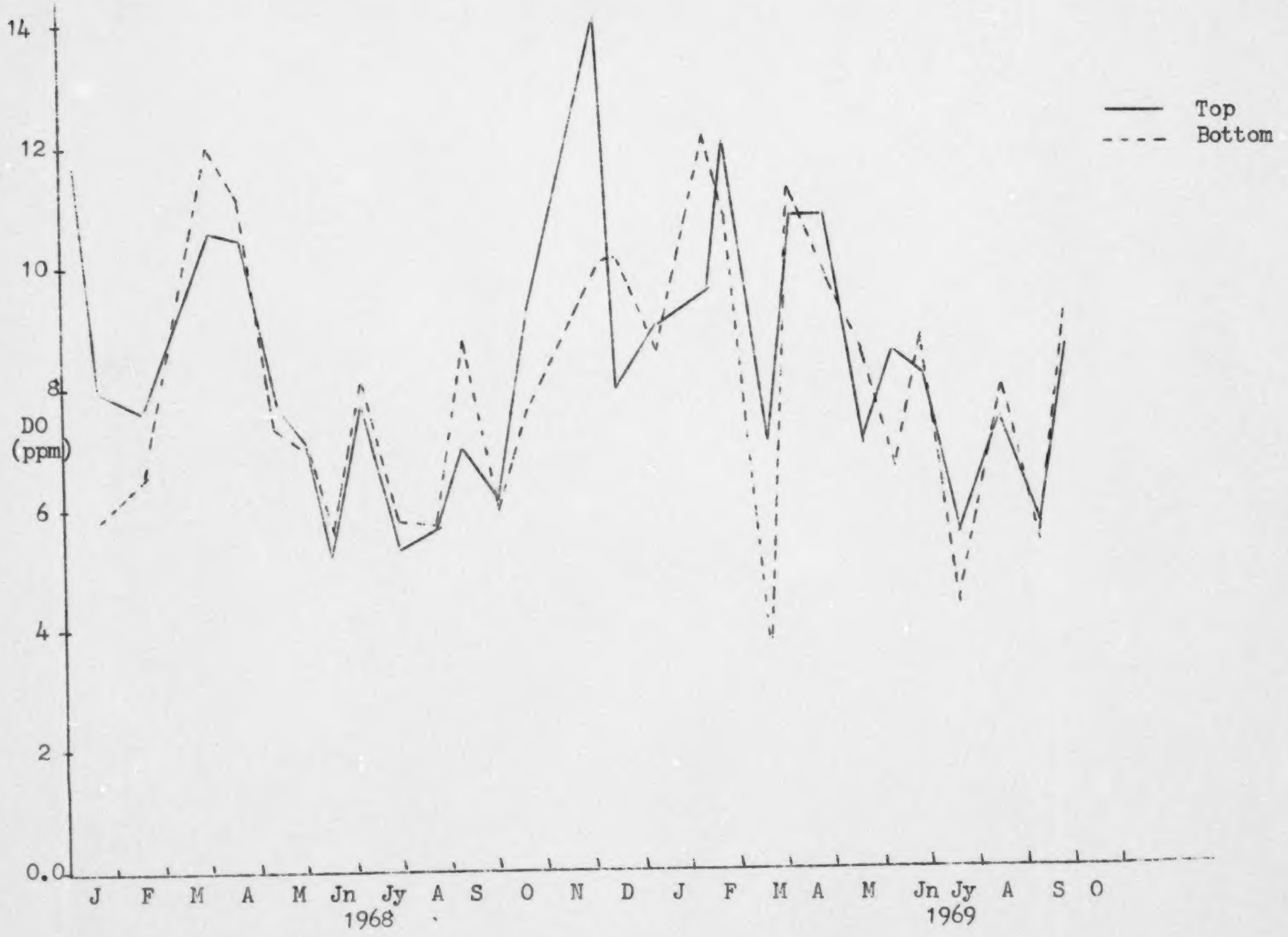


Figure. 18. Connecticut River Dissolved Oxygen (ppm); Station 6. Prethermal Period.

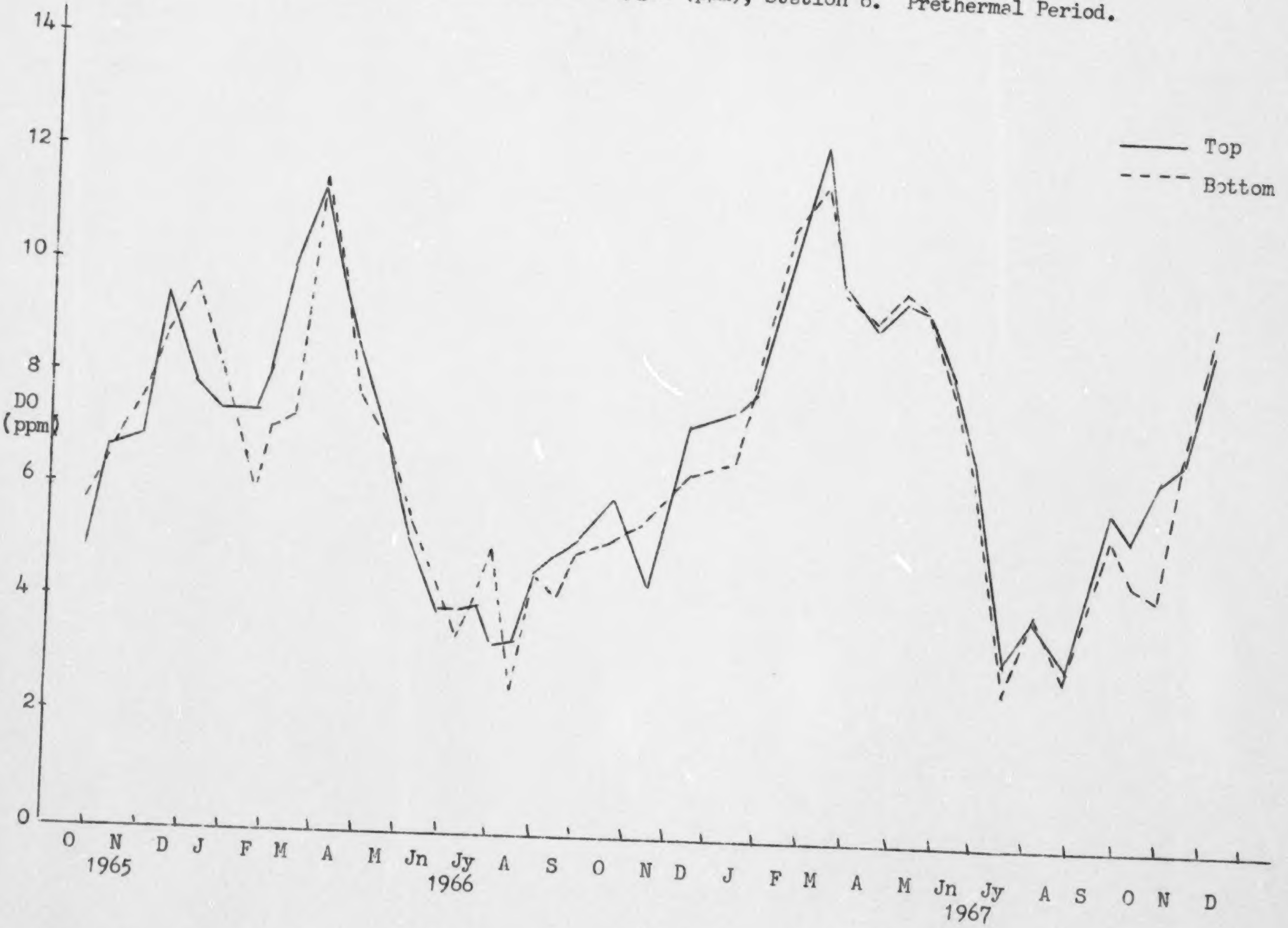


Figure 19. Connecticut River Dissolved Oxygen (ppm); Station 6. Thermal Period.

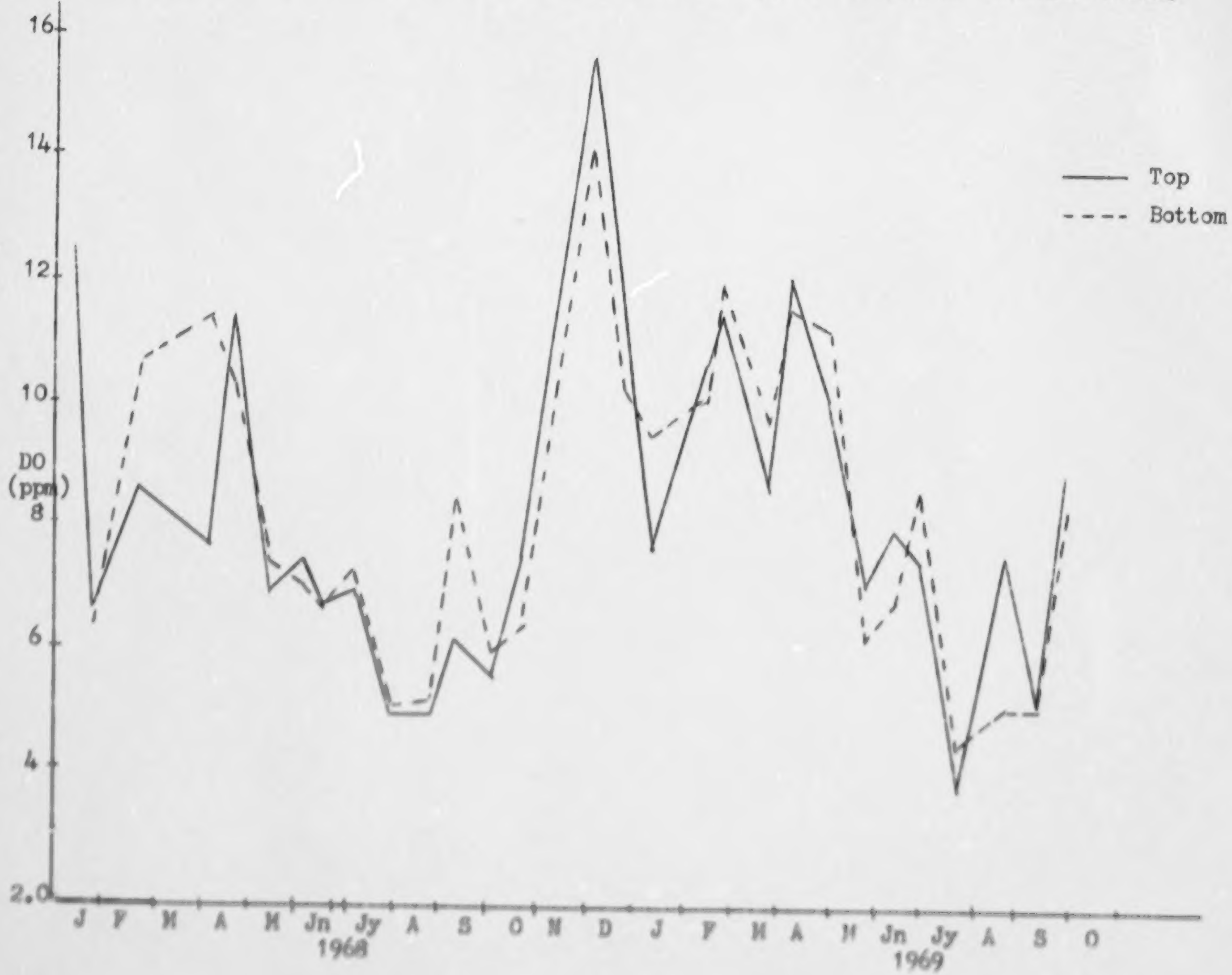


Figure 20. Connecticut River Dissolved Oxygen (ppm); Stations 7 & B. Prethermal Period.

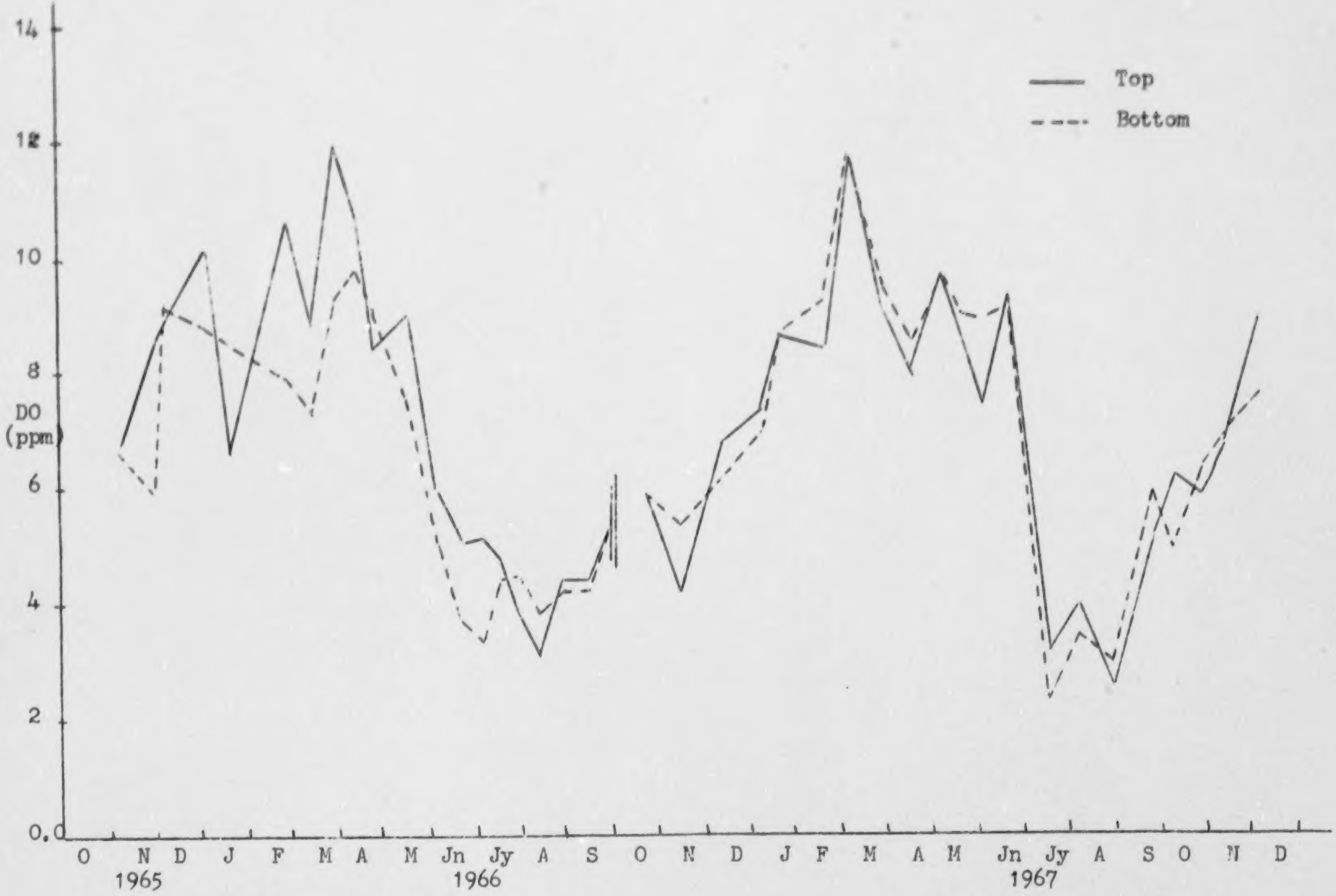
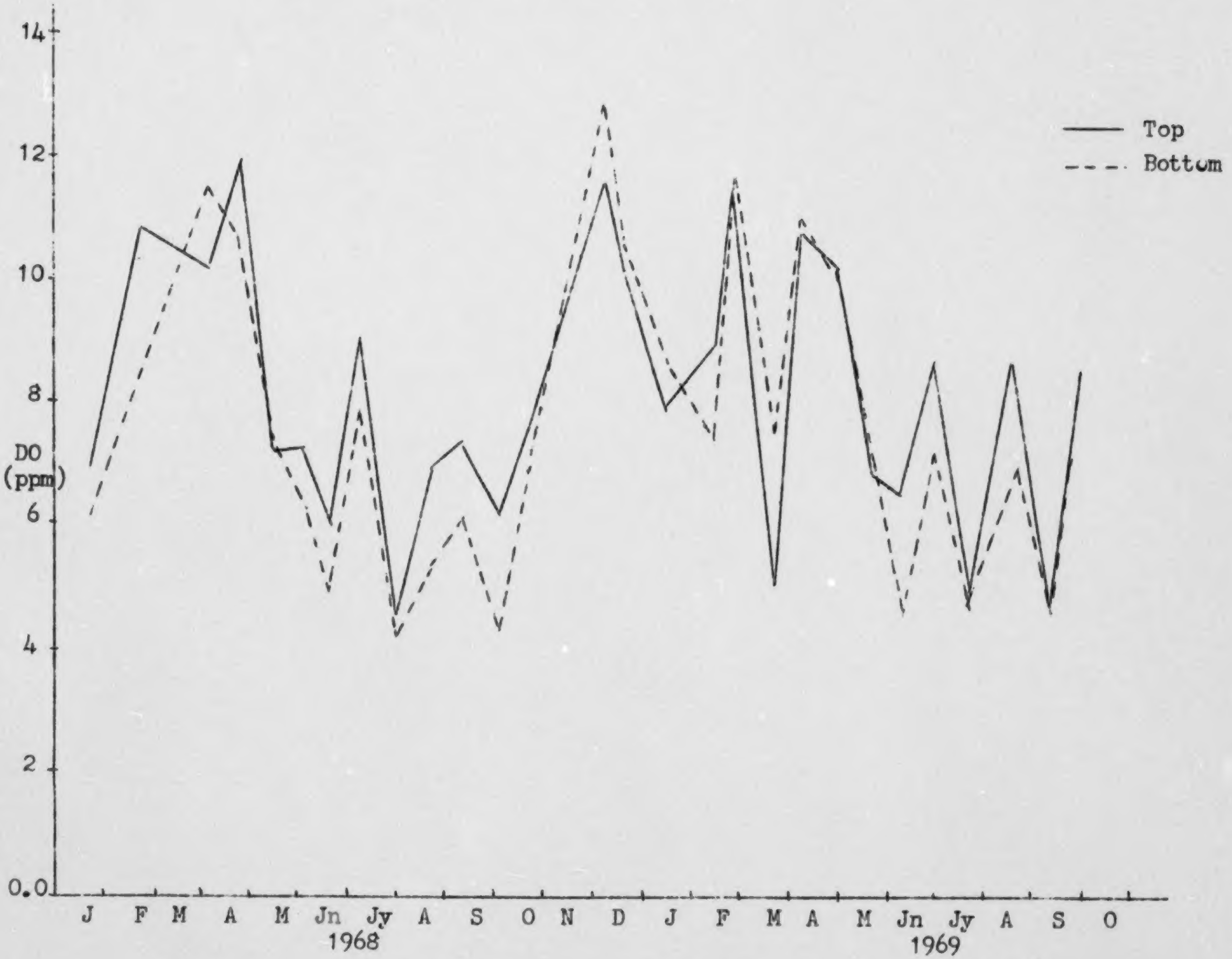


Figure 21. Connecticut River Dissolved Oxygen (ppm); Station B. Thermal Period.



in the Connecticut River during both prethermal and thermal periods lend credence to this possibility. The role of increased phytoplankton populations in this diurnal fluctuation in D.O. levels is discussed below.

If one considers the thermal data from all stations certain generalities can be made. Seasonal highs and lows are not as obvious and imaginary trend lines would be less peaked than for prethermal records. Secondly, top and bottom samples do not coincide as well as in prethermal readings. Station B, our assumed "control", shows as much of these variations as the other stations. Essentially, prethermal and thermal readings for all stations form two patterns with the latter being more variable and less well-defined.

In comparing "prethermal" and "thermal" data for each station, the most striking observation is that D.O. values are consistently higher at all stations during the thermal period and may be reflected by increased phytoplankton numbers.

It is a basic tenet of chemistry that, all other factors being constant, water holds less D.O. as the temperature rises. Obviously, other factors are operative in the system studied here. Thermal D.O. levels fell to below 4 ppm in 2 isolated samples while reaching approximately 12 ppm on several occasions.

We have no definitive explanation for the higher D.O. readings after plant operation. It is quite possible that turbulence (aeration) as the water is discharged from the plant may be responsible for our observations as well as an algal effect.

Considerable literature is available on the relationship of D.O. to fish activity (e.g., 4, 15). Some general principles have been summarized (8, 52) and indicate that increased D.O. may be necessary for fish survival in warm water since metabolic processes increase and require greater quantities of D.O. to maintain this activity. Some relevent observations have been made on fish (white catfish and brown bullheads) in the CYAPC discharge canal (18).

Fish that overwintered in the heated effluent were in poorer condition and lower in weight when compared with counterparts at the mouth of the Salmon River. No D.O. values are given for the effluent proper but are no doubt significant in the metabolic processes occurring in these fish.

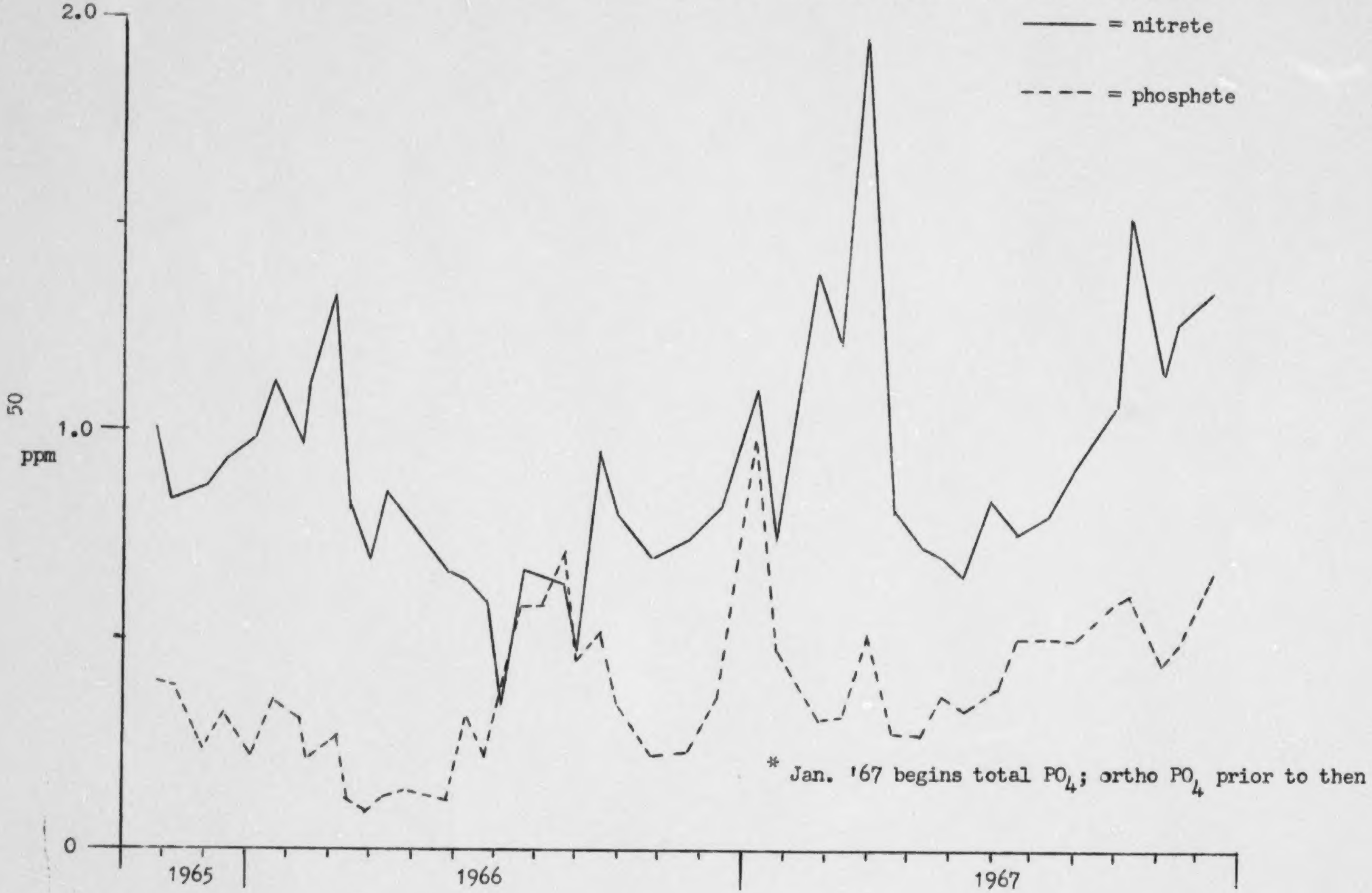
One report (54) suggests a minimum of 5mg/l of D.O. as the minimum oxygen criterion in an American shad water quality standard. With this hypothetical figure, Figs. 14-21 show that thermal D.O. values are consistently above this level while many prethermal readings are below. We emphasize again that our readings were all made during daylight hours; night values may be significantly lower.

d. Nitrate and Phosphate. Nitrate values in the Connecticut River ranged from 0 to 2 ppm (average <1.0ppm) in prethermal and thermal periods. Total phosphate readings varied from 0 to 1.5 ppm (average <1.0 ppm) for the study period. Considering that the River flows through a highly agricultural region and receives large amounts of variously-treated domestic and industrial wastes, these values do not appear inordinately high. The potential productivity of any body of water is to a great extent determined by the natural fertility of the land over which the runoff drains and by contributions from civilization. Constant introduction of nitrate and phosphate insures the presence of these nutrients and is reflected in their ability to support annual blooms of phytoplankton in the River.

Prethermal nitrate readings, in general, tended to follow seasonal patterns with lowest values (less than 1 ppm) recorded during warmer months and greatest amounts occurring in the winter. Phosphate levels, both total and ortho, are somewhat similar although less pronounced. These "normal" fluctuations are probably a reflection of both increased runoff-which adds nutrients, and algal activity at various times of the year which depletes nitrate and phosphate levels.

Thermal period values for both chemical parameters are similar to pre-

Fig. 22. Average (T & B) nitrate and phosphate; Station 1; Prethermal period



* Jan. '67 begins total PO_4; ortho PO_4 prior to then

Fig. 23. Average (T & B) nitrate and total phosphate; Station 1; Thermal period

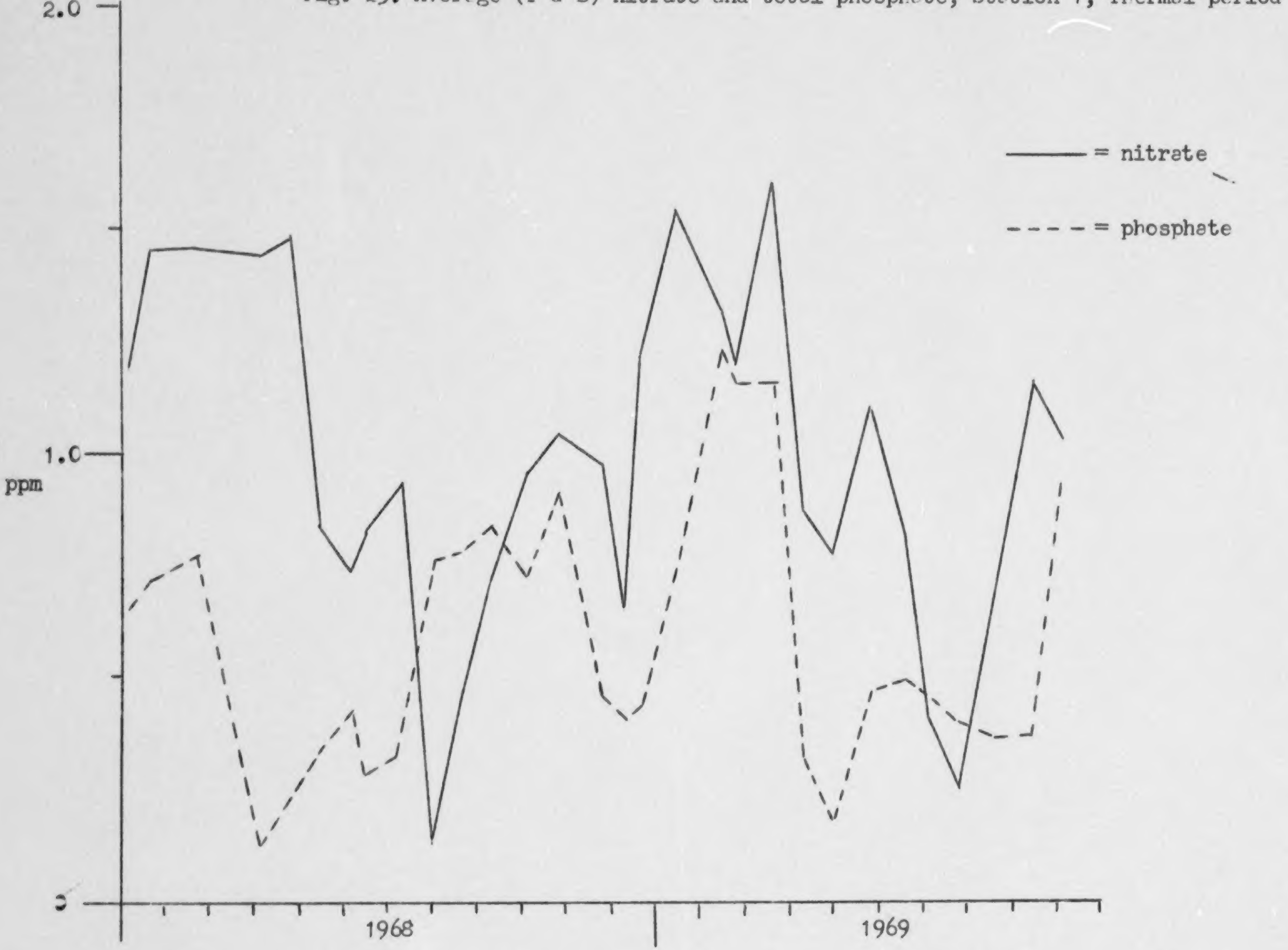
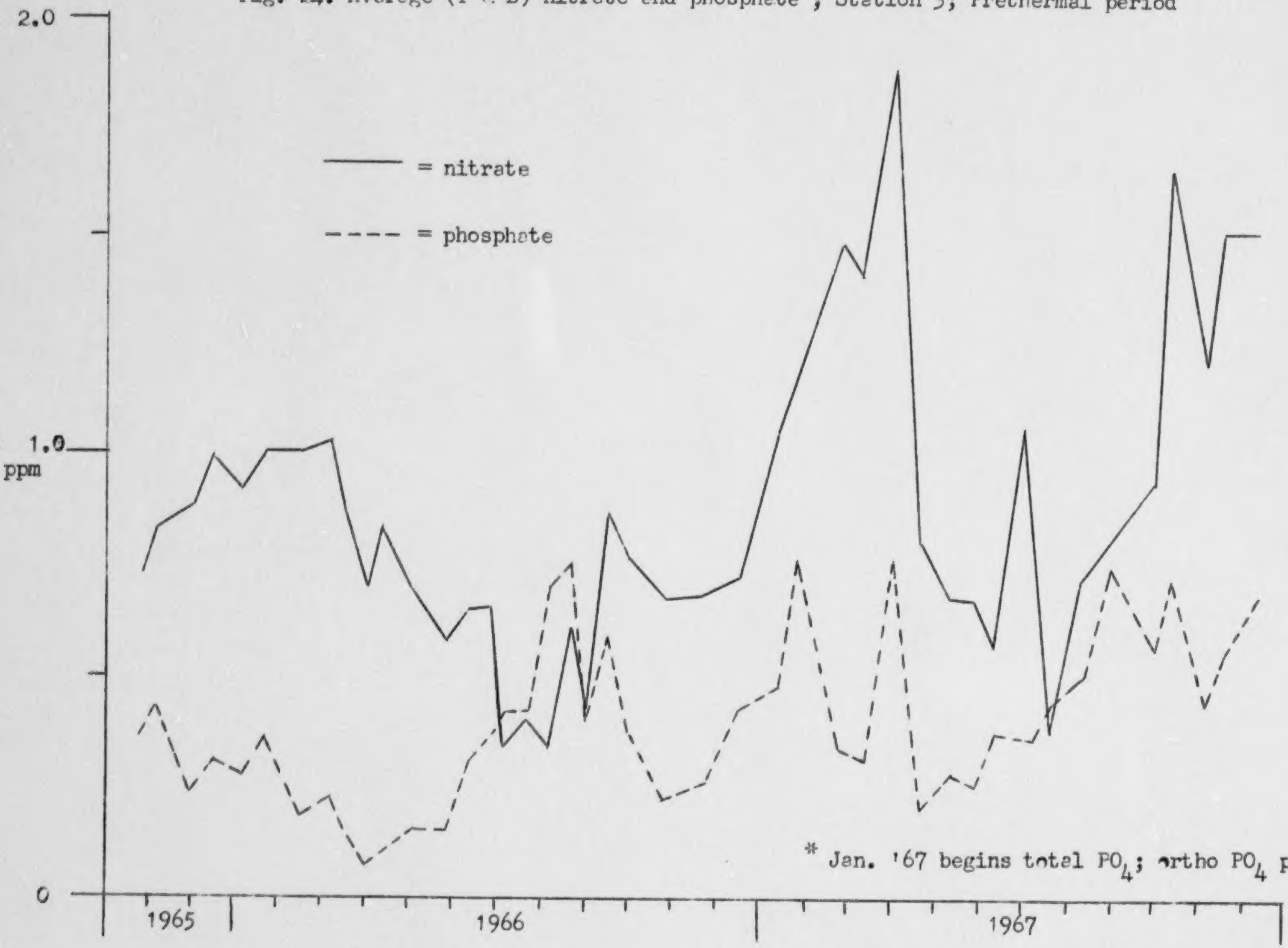


Fig. 24. Average (T & B) nitrate and phosphate*; Station 3; Prethermal period



* Jan. '67 begins total PO_4; ortho PO_4 prior to then

Fig. 25. Average (T & B) nitrate and phosphate; Station 3; Thermal period

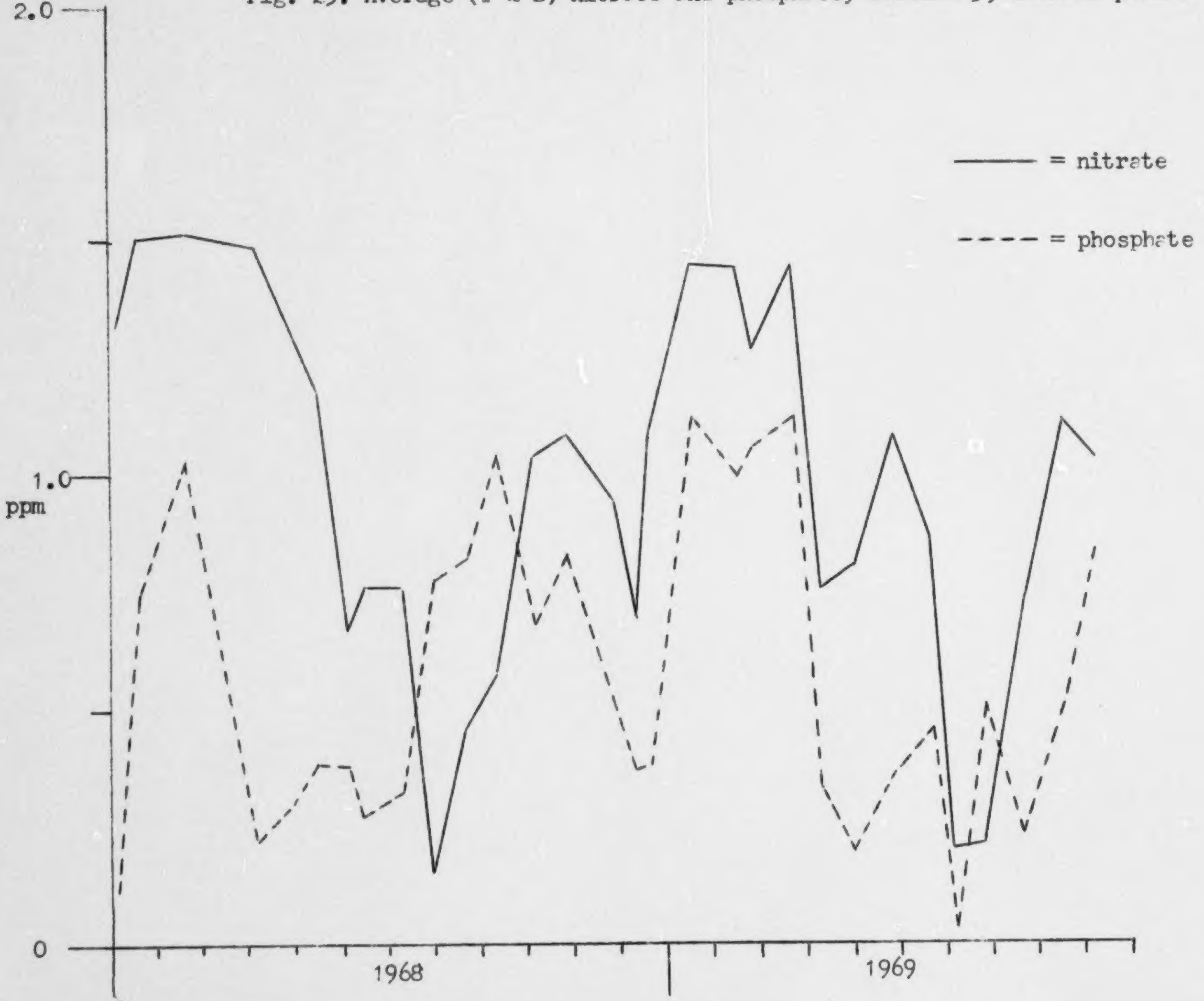
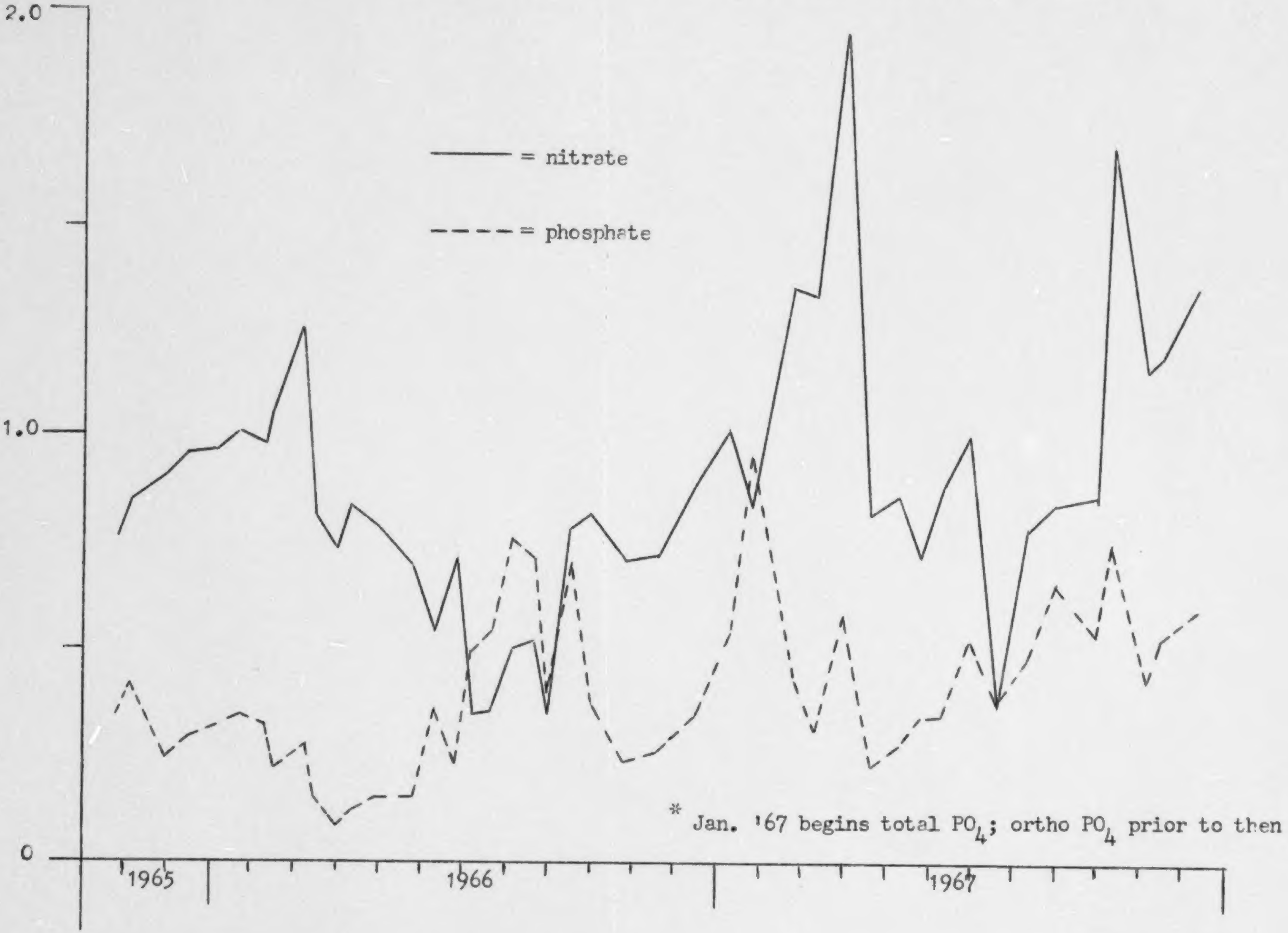


Fig. 26. Average (T & B) nitrate and phosphate*; Station 6; Prethermal period



* Jan. '67 begins total PO_4; ortho PO_4 prior to then

Fig. 27. Average (T & B) nitrate and phosphate; Station 6; Thermal period

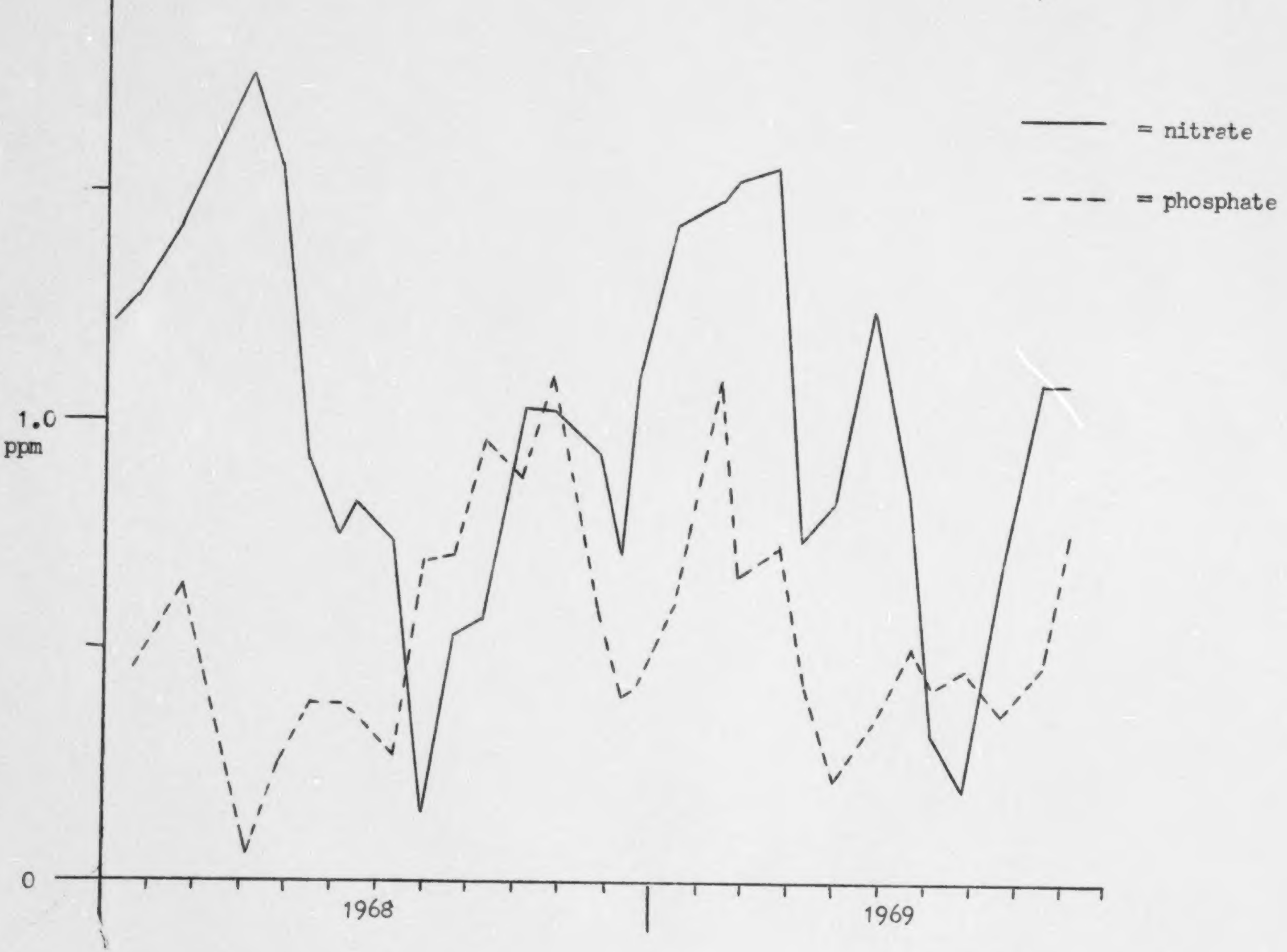
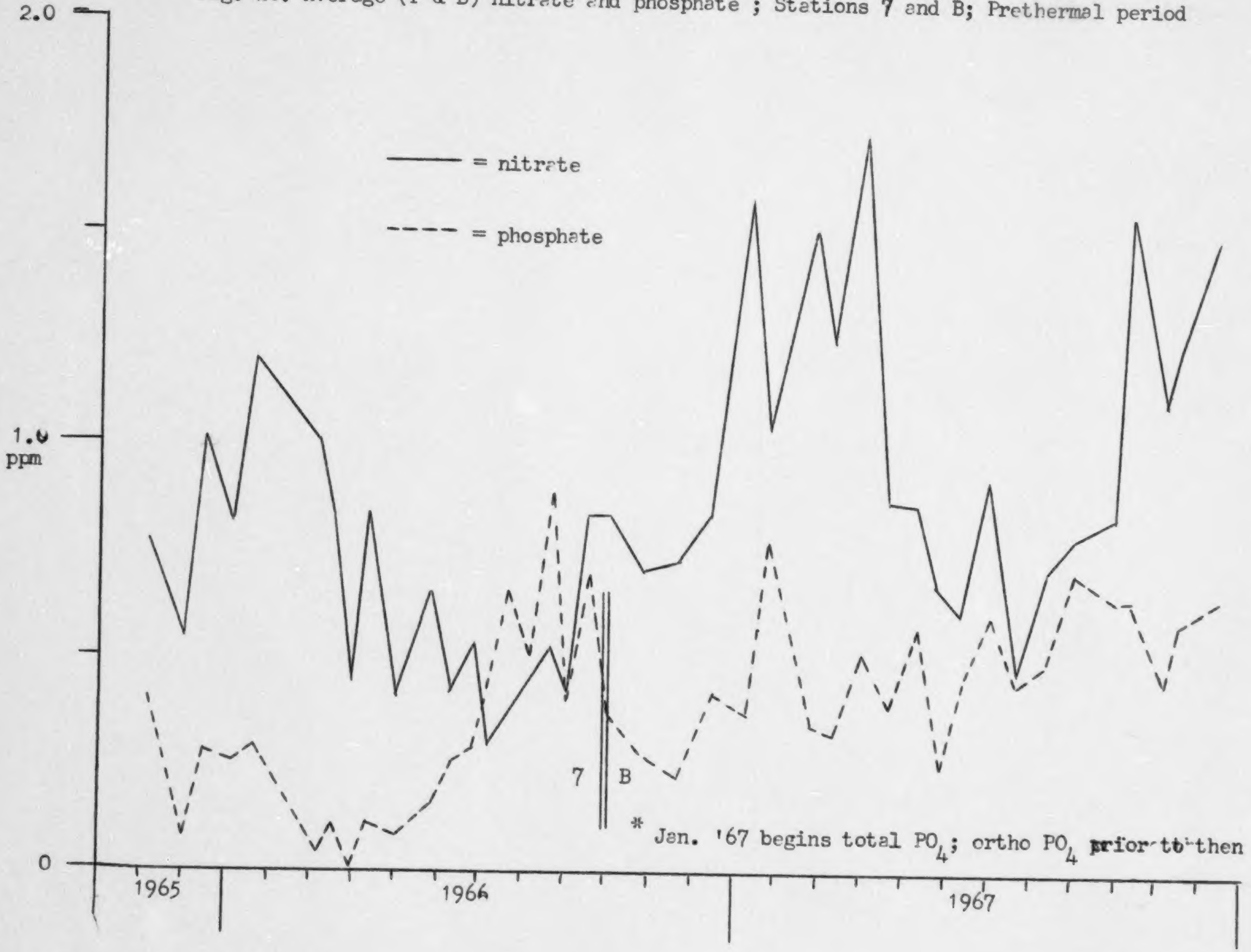
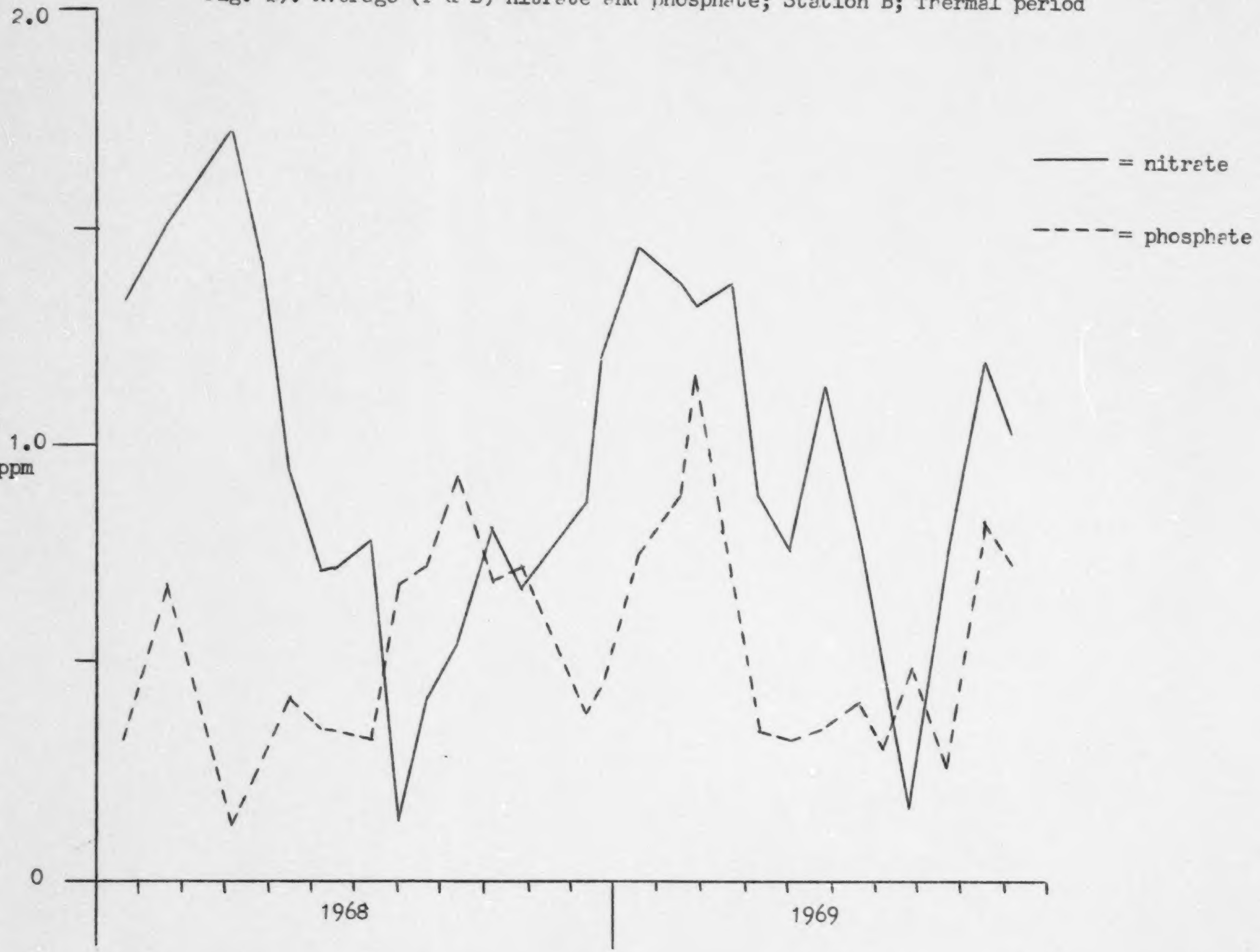


Fig. 28. Average (T & B) nitrate and phosphate*; Stations 7 and B; Prethermal period



* Jan. '67 begins total PO_4; ortho PO_4 prior to then

Fig. 29. Average (T & B) nitrate and phosphate; Station B; Thermal period



thermal observations although the figures show more variation. Thermal values are similar and reflected at all stations. Thus, we cannot ascribe higher or lower changes in nitrate and phosphate values to initiation of CYAPC activity. When data are available for a long stretch of a river (55), levels of variables such as nitrate and phosphate can be followed as a function of water use. In the relatively short distance studied here, neither parameter showed significant variation either between stations or in "before" and "after" analyses.

e. Other Chemical Determinations. Ammonia-nitrogen and total (Kjehdahl) nitrogen values were determined less frequently than nitrate-nitrogen and phosphate-phosphorous above. All readings obtained, with one exception, were less than 1 ppm and do not suggest any indication of unusually high values as encountered in similar natural bodies of water. In general, the greatest amounts of these forms of nitrogen were found during the winter months with lowest values obtained during summer. These data follow those above and, again, provide no indication of thermal influence on their quantitative distribution.

The few chlorophyll determinations made during 1967 ranged from a low of 6 mg/m^3 for chlorophylls a and b, while chlorophyll c was always present in as great or greater concentrations than the other two pigments and at levels as high as 50 mg/m^3. These values confirm our data below on the dominance of the diatoms in the Connecticut River since chlorophylls a and b are not characteristic of this group of phytoplankton. Chlorophyll determinations were too few to allow any other conclusions to be made.

3. Algae (Phytoplankton and Phycoperiphyton)

Algae were identified according to recent monographs (55-61). Quantitative and qualitative observations were analyzed statistically and several computerized routines were developed. Statistical methods considered the data for significant variations and effects by using analysis of variance

(ANOVA) to test the hypothesis $H:u_1=u_k$, multiple regression and correlation. The ANOVA model ($H:u_1=u_k$) used in the following discussion is a linear statistical model which assumes that values are assigned completely at random and the variances are homogenous (62). Symbols used signify the following:

H = hypothesis

u_1 = mean of the populations to which all other population means are compared.

u_k = means of the other populations used in the analysis where k is the number of other means.

The multiple regression analysis is based on the formula for a straight line. It is used here to determine if a change in one environmental factor affects a corresponding change in another factor. Each chemical-physical factor was analysed for its effect on the total number of phytoplankters. From this analysis, the correlation coefficient (r) is derived. The r value has a range from -1 through 0 to +1. A plus (+) indicated that as one environmental factor increased, so did the other in direct proportion. A minus (-) indicated that as the one environmental factor increased the other factor decreased in indirect proportion. The closer r was to 0, the less significant one factor appeared to be in effecting a change in the other. Mathematically, r is an indication of the magnitude of the slope of the regression line. Correlation coefficients above ± 0.70 are considered to be mathematically highly significant. However, in natural populations the significance values may be lower and, as will be shown, if the r value for a given environmental factor increased over a period of time, this indicated increasing importance of that factor in the environment if the number of samples remains constant.

Multiple regression and correlation were performed using the various chemical and physical parameters as independent variables and the phytoplankton quantitative counts as the dependent variable. The Jaccard (63) Coefficient of Community (C.C.) and the Koch (64) Index of Biotal Dispersity (I.B.D.) were used to compare community compositions during the period when the plankton tows and periphyton analyses were made.

Generally, only data from Stations 1, 3 and 6 will be presented; analyses of Station 8 has shown it to be influenced by the tide and the subsequent increase in salinity appears to mask any possible temperature influences. Station 1 has been chosen as the "control" station as it was most exemplary of ambient conditions. A series of ANOVA calculations were performed to test the variation between top and bottom samples at station 1, 3 and 6. The variation between top and bottom was not significant and the hypothesis $(H:u_l=u_k)$ was accepted. This relative homogeneity would be advantageous if the thermal effluent were mixed and not layered.

Since temperature profiles made between station 1 and 6 indicated that thermal effluent was confined to the upper 3 feet of surface water, all data, computations and comparisons are made for surface waters, except for Fig. 33B.

ANOVA tests were applied to the data (1) at each station top and bottom, (2) at each station top, (3) between station 1 and 3, (4) between station 3 and 6 and (5) all stations top and bottom. All analyses accepted the hypothesis that $H:u_l=u_k$. Since natural populations have wide fluctuations in numbers of individuals in response to many environmental parameters, the effect of any given exterior influence can be masked. Figures 30, 31 and 32 are density graphs of the total phytoplankton counts at each station during the entire study. If Figs. 31 and 32 are superimposed on Fig. 30 (station 1) the general trends of increase and decrease at each station are almost identical. The ANOVA tests show that when the entire study is computed together there is no significant difference between prethermal and thermal data.

Table 3 has been prepared to show the numerical values from which Figs. 30, 31 and 32 were made. While no attempt will be made to explain each and every fluctuation, the overall analysis showed that the phytoplankton counts were extremely high at all stations, and far exceed the definition for a bloom of 500 individuals per milliliter of raw water (65). The phytoplankton

Fig. 30. Phytoplankton density in the Connecticut River; Station 1; 10/65 - 10/69

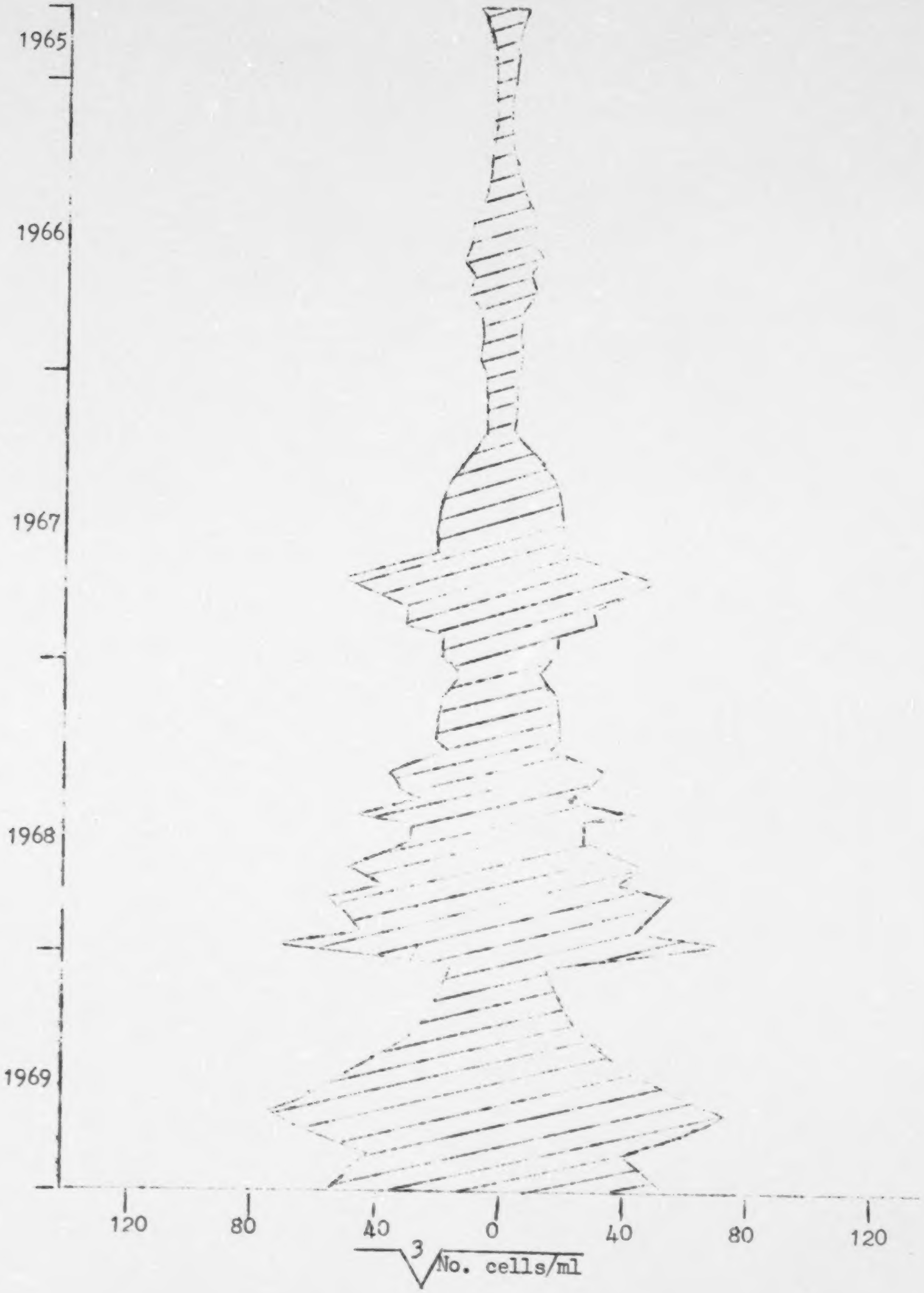


Fig. 31. Phytoplankton density in the Connecticut River; Station 3; 10/65 - 10/69

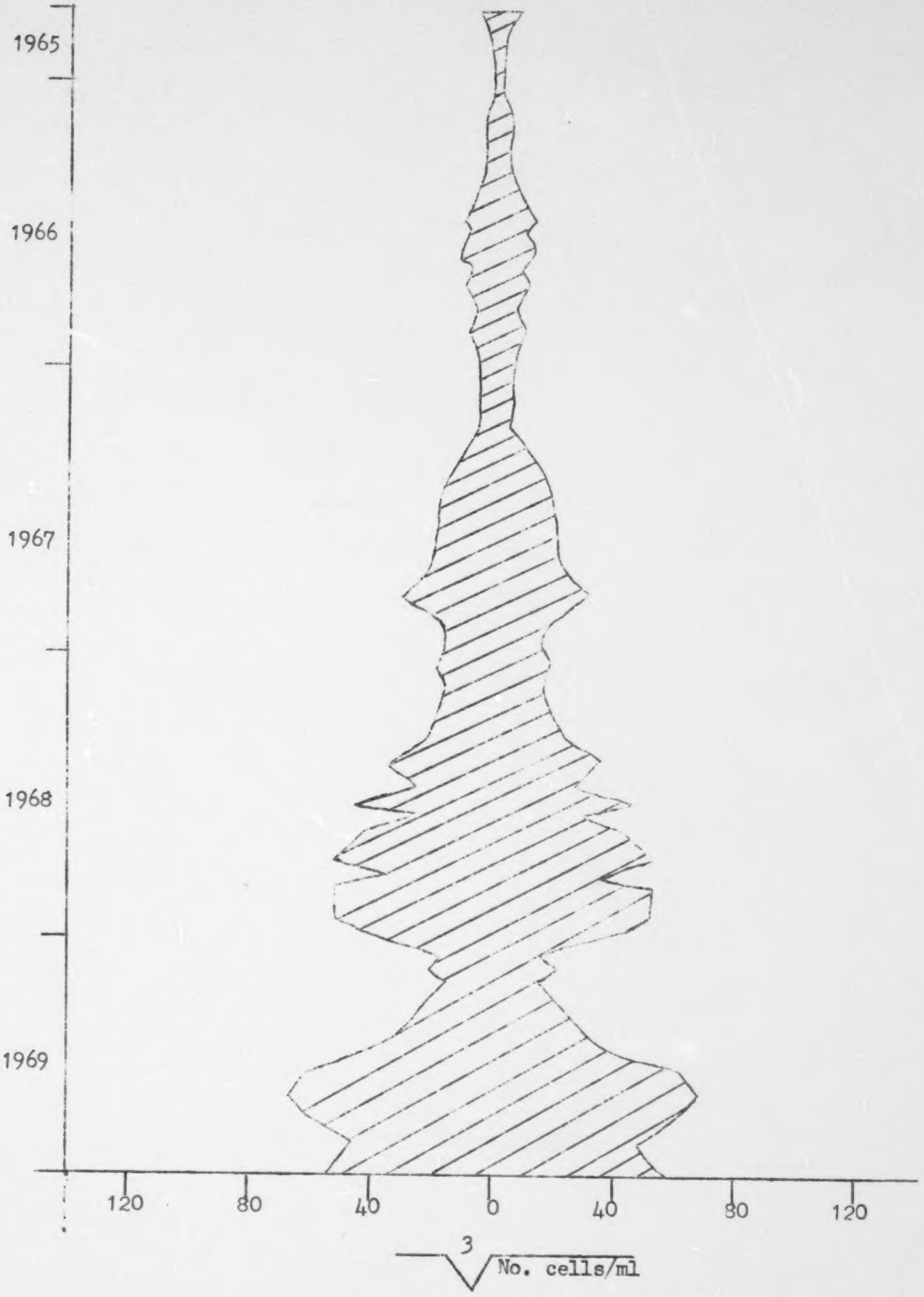


Fig. 32. Phytoplankton density in the Connecticut River; Station 6; 10/65 - 10/69

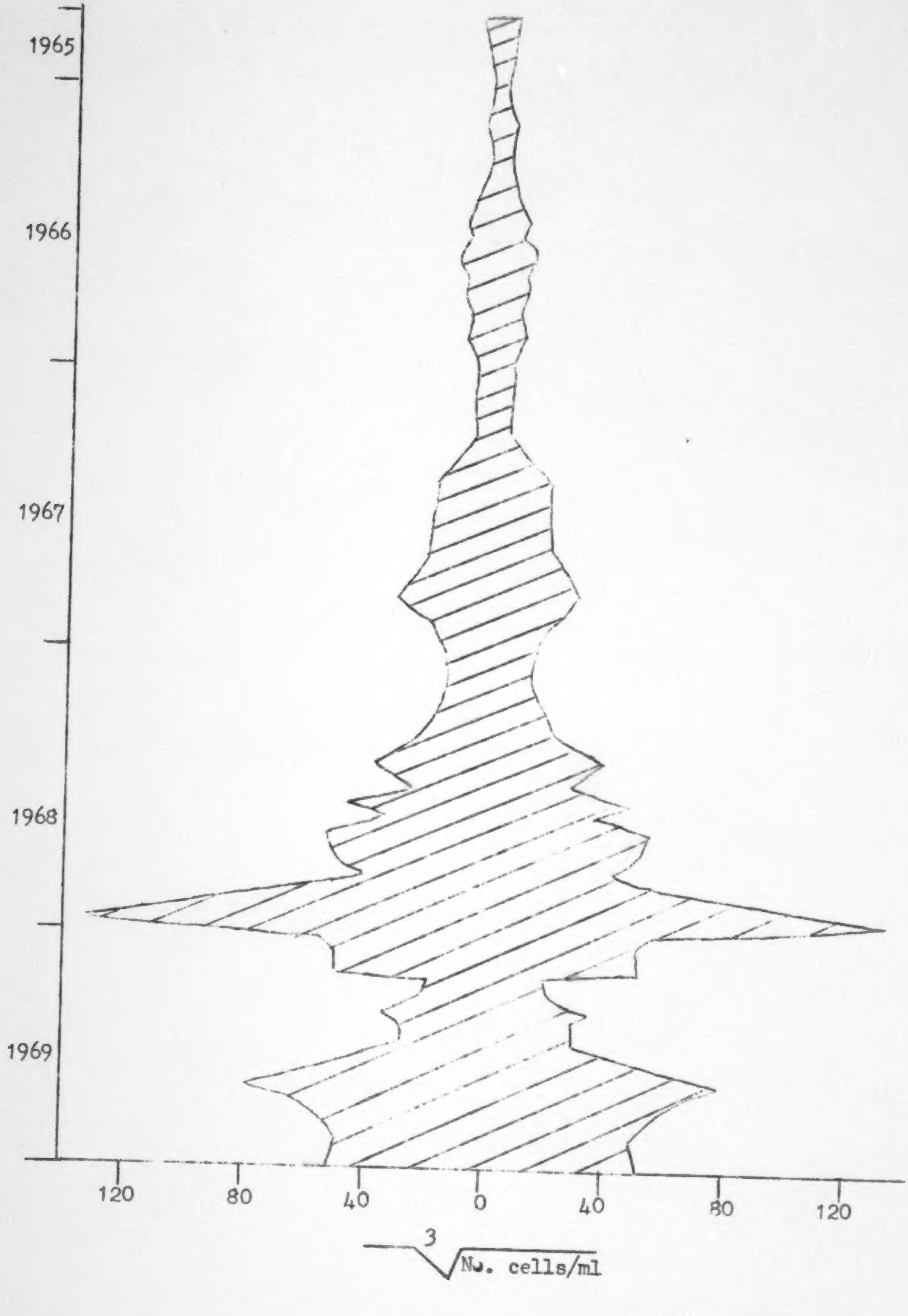


TABLE 3. Total Phytoplankton (10^3 cells/ml).

		Top				Bottom			
	Date	1	3	6	B	1	3	6	B
Fall	10/26/65	1.0	1.3	.8	-	.8	.8	1.0	-
	11/9	.4	.2	.3		.2	.3	.3	
	11/30	.1	.1	.1		.1	.1	.1	
	12/14	.0	.1	.1		.1	.0	.0	
Winter	1/4/66	.1	.1	.1		.1	.1	.1	
	1/20	.0	.0	.0		.0	.0	.0	
	2/15	.3	.3	.4		.3	.3	.4	
	3/1	.2	.2	.2		.2	.1	.3	
	3/15	.1	.1	.2		.2	.2	.2	
Spring	3/29	.5	.6	.6		.5	.3	.4	
	4/12	.3	.2	.3		.4	.4	.4	
	4/26	.4	.5	.6		.5	.4	.6	
	5/24	1.2	1.7	1.3		1.9	1.2	1.3	
	6/7	4.1	4.9	5.7		4.9	4.3	5.1	
Summer	6/21	10.2	10.8	11.1		-	-	-	
	7/5	3.8	4.4	5.0		3.4	3.1	4.5	
	7/19	8.2	8.7	10.0		6.1	8.2	7.1	
	8/2	12.6	13.1	13.0		11.4	11.2	11.2	
	8/16	8.4	9.3	9.2		8.2	8.6	8.1	
	8/30	4.1	4.4	4.7		4.5	3.1	3.7	
	9/13	7.8	7.2	8.0		5.8	6.3	6.4	
Fall	9/28	9.2	8.8	8.6		8.8	8.5	7.0	
	10/25	1.7	2.0	3.2	2.6	1.1	3.3	3.0	3.6
	11/15	-	-	4.9	4.2	2.8	5.4	4.5	3.6
	12/13	1.4	1.7	1.5	1.4	1.2	-	1.7	1.7
Winter	1/10/67	1.6	1.5	1.3	1.0	1.5	1.2	1.3	1.3
	1/24	.8	1.4	1.4	1.7	.8	1.0	1.3	1.9
	2/21	1.1	2.4	1.3	1.6	1.0	1.3	1.7	1.9
	3/7	1.9	1.4	1.1	.8	1.2	1.4	1.0	1.3
Spring	4/18	Samples Lost!							
	5/9	38.2	29.6	47.2	42.2	35.7	33.2	31.0	40.2
	5/23	36.2	41.7	35.1	53.3	49.0	45.1	49.1	51.1
	6/6	51.5	45.0	55.0	70.3	59.2	64.8	68.5	57.9
Summer	6/27	6.7	7.0	8.6	4.8	7.5	6.5	4.8	6.3
	7/18	7.3	5.2	5.6	8.1	4.3	4.8	5.5	5.4
	8/8	39.9	29.3	34.3	28.8	44.6	45.4	35.3	41.0
	8/29	64.7	63.6	59.7	74.6	84.0	38.7	76.7	157.1
Fall Prethermal	9/27	119.7	78.0	-	103.4	115.5	87.5	101.0	114.6
	10/10	261.9	210.0	215.7	275.2	181.1	322.9	398.3	359.8
	11/1	75.0	81.7	93.3	118.9	85.5	127.4	98.6	206.8
	11/14	46.8	40.2	44.4	53.1	56.6	50.6	58.9	76.8
	12/6	44.1	29.3	33.2	20.1	36.1	65.7	34.6	29.7

TABLE 3. Continued.

Winter	1/9/68			Ice				Ice		
	1/23	Thermal	13.2	41.4	21.3	23.8	40.1	29.6	26.7	21.3
	2/20		38.5	29.6	30.2	-	47.8	63.3	26.3	66.4
	3/2		65.5	70.1	86.2	108.6	55.5	91.3	79.6	102.4
Spring	4/24		32.6	57.4	61.3	64.1	49.0	61.7	71.1	52.0
	5/15		348.1	355.2	393.8	216.9	287.3	274.8	364.6	281.3
	6/3		243.0	172.3	147.1	234.1	305.6	126.1	217.8	223.9
	6/18		88.2	95.9	104.0	86.6	108.5	109.7	84.9	84.5
Summer	7/9		723.5	668.6	788.5	731.6	697.0	599.5	768.2	873.9
	7/30		148.3	189.0	286.5	268.3	213.4	304.8	266.2	254.0
	8/20		144.3	629.6	1,373.8	1,396.1	585.3	782.4	1,526.2	1,097.8
	9/10		770.2	1,095.4	1,005.9	753.9	1,298.6	1,345.3	949.0	1,003.9
Fall	10/2		370.2	362.1	625.1	493.0	357.3	584.9	523.1	476.7
	10/23		1,152.3	1,124.0	1,178.2	1,149.8	1,190.3	831.6	1,177.1	1,237.2
	11/25		-	180.5	86.2	-	-	199.2	187.0	-
	12/9		615.4	1,122.2	19,470.5	2,455.5	995.5	1,369.5	2,045.2	1,955.1
	12/18		2,546.8	636.7	1,434.3	657.2	503.2	677.8	492.9	-
Winter	1/15/69		18.4	33.5	119.9	57.0	18.3	78.2	64.0	57.9
	2/13		34.5	59.9	123.0	68.1	57.9	14.2	98.6	57.8
	2/26		34.5	28.5	44.7	21.3	29.5	36.6	28.4	28.4
	3/20		78.0	78.2	81.3	50.8	133.1	179.6	119.9	58.9
Spring	4/9		146.3	173.8	306.8	154.8	131.0	191.5	88.0	203.2
	4/30		99.5	138.1	183.9	158.6	136.1	109.8	210.9	157.4
	5/21		458.9	363.8	435.9	369.8	1,184.6	414.9	373.9	404.4
	6/17		1,264.0	1,914.3	1,377.8	1,564.8	1,412.3	1,867.6	1,388.0	1,500.0
Summer	7/1		2,050.5	2,325.1	3,759.6	3,542.1	2,176.5	3,314.5	3,779.9	3,786.0
	7/22		3,946.5	2,463.0	2,235.4	2,109.4	4,267.6	1,879.8	1,713.1	1,568.9
	8/19		1,904.2	1,808.7	1,420.5	1,170.5	1,203.1	1,345.3	963.3	1,016.1
	9/11		542.6	907.4	879.9	421.7	703.1	644.2	751.9	274.3
	10/1		-	1,280.3	1,117.7	758.0	920.6	1,040.5	1,012.0	916.5

showed a definite increase in total numbers at all stations over the entire period of sampling. Enrichment of the river upstream by treated and untreated sewage effluent coupled with constant increase in overall land runoff resulting in higher river flows during the study period were probably factors in these quantitative increases.

Ortho-phosphate levels were above those suggested as stimulatory for algal blooms (66) in flowing water (0.01-0.03 mg/liter). Nitrate-nitrogen was present constantly in adequate concentrations.

Since it was noted that the total number of phytoplankters increased over the period of study, tests other than just variance were applied. If the variance test was the only one applied to the data then this work would mirror other conclusions (67-70) in which no significant variation or change in the quantitative structure of the plankton passing through a thermal discharge area was noted.

It was evident through microscopic observation that differences both in numbers of organisms and types of species were occurring. This was noted especially during periods of low effluent temperatures. Other comparative analyses of the data were performed to test for these apparent differences, and to assess whether they were anomalies of sampling or actual manifestations of the thermal enrichment.

Tests were designed to analyse the phytoplankton by screening for the effect of temperature change. All data from the thermal period of the study were assembled and data selected for sampling periods when the effluent temperature was 5° F or more above ambient. Data from station 1 at the same period were used as a "control". The temperature stands out as a significant parameter when correlation coefficients are compared. Table 4 lists correlation coefficients for station 1, station 3 and station 1 and 3 together. The mean of each parameter is listed also. A survey of the means listed in Table 4 show that the mean temperature at station 3 has the only significant

TABLE 4. Comparison of correlation coefficient (r) and means ($\overline{X}$) of six parameters during thermal conditions. (Data selected for samples at Station 3 when the temperature exceeded ambient by 3° C or more).

	Station (r)		Station ($\overline{X}$)		Combined	
Parameter	1	3	1	3	r	$\overline{X}$
Temperature	.40071	.70073	13.24	18.88	.47931	16.13
pH	.25034	.04224	6.71	6.69	.16709	6.70
D.O.	-.17930	-.24634	8.32	8.12	-.20011	8.22
NO_3	-.47182	-.48198	1.03	0.97	-.46396	1.00
PO_4	-.00417	-.14596	0.23	0.31	-.08733	.27
o/oo	-.04434	-.32814	0.13	0.11	-.13711	.12

r = correlation coefficient

$\overline{X}$ = mean

change relative to station 1. The other parameters are similar. Phosphate means are slightly divergent but the "r" value indicates practically no correlation. The salinity "r" value at station 3 seems to be different and may indicate a retardation of the phytoplankton growth slightly so that the total effect of the thermal effluent may be depressed. However, the high positive temperature correlation indicated that temperature is very important during this period of analysis. Fig. 33A is presented to demonstrate the density curves and relative agreement in general ecological trends for the data selected for analysis and presented in Table 3. However, in comparing station 3 to station 1, it was noted that the former had less fluctuations and the quantitative measure of the community appeared to be maintained at a higher level. In comparison to Table 4,the temperature appeared to be this modifying parameter. Station 6 (Fig. 33A) also reflected the influences important at station 3, though this station seems to be returning to ambient conditions represented by station 1. The "r" values (Fig. 33A) characterize the importance of the temperature in respect to number of cells of phytoplankton per ml. As the correlation coefficient rose at station 3, so did the relative number of phytoplankton and was indicative of a stimulatory effect.

If thermal discharges are exerting an influence at station 3, comparing similar dates during prethermal and thermal conditions may show some significant differences. Sampling dates during the period April to November 1967 (prethermal) were compared to 1968 (thermal). The April to November period in 1968 showed thermal releases most uniformly above ambient and the greatest number of samples. These data are plotted in Fig. 33B, which was prepared for stations 1 and 3 covering the same sampling dates in 1967 and 1968. Station 1 showed more uniform curves, while the station 3 plots for 1968 (thermal) were less similar to the 1967 prethermal curve at the same station. ANOVA tests were run on the data for station 1 and station 3. The hypothesis $H:u_1=u_k$ was accepted at the 95% level of confidence for station 1, indicating

Figure 33A. Comparison of phytoplankton density for surface waters at Station 1, 3, and 6 during thermal conditions. Data are represented for sampling periods when the temperature at Station 3 exceeded ambient by 3°C or more.

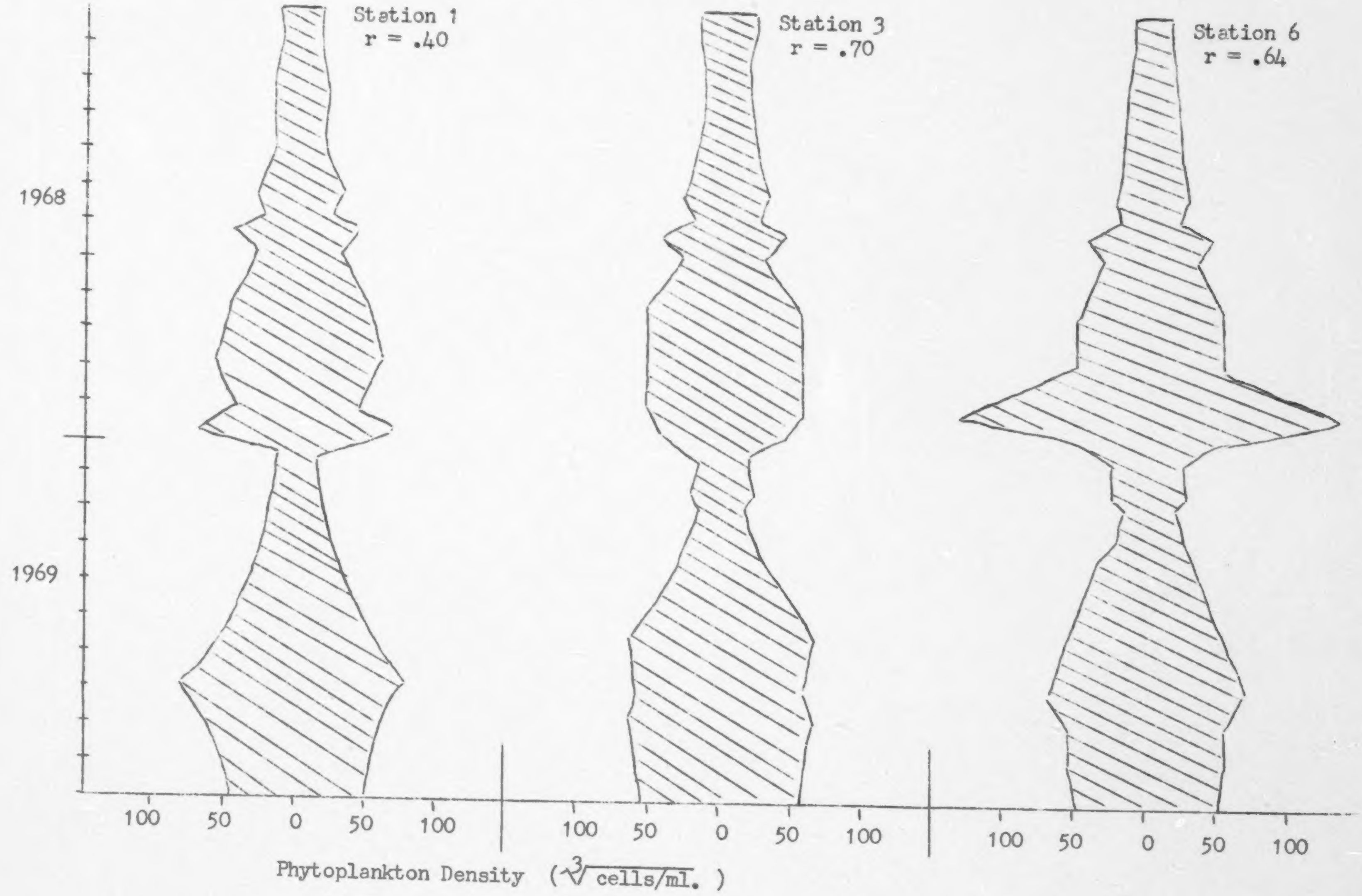
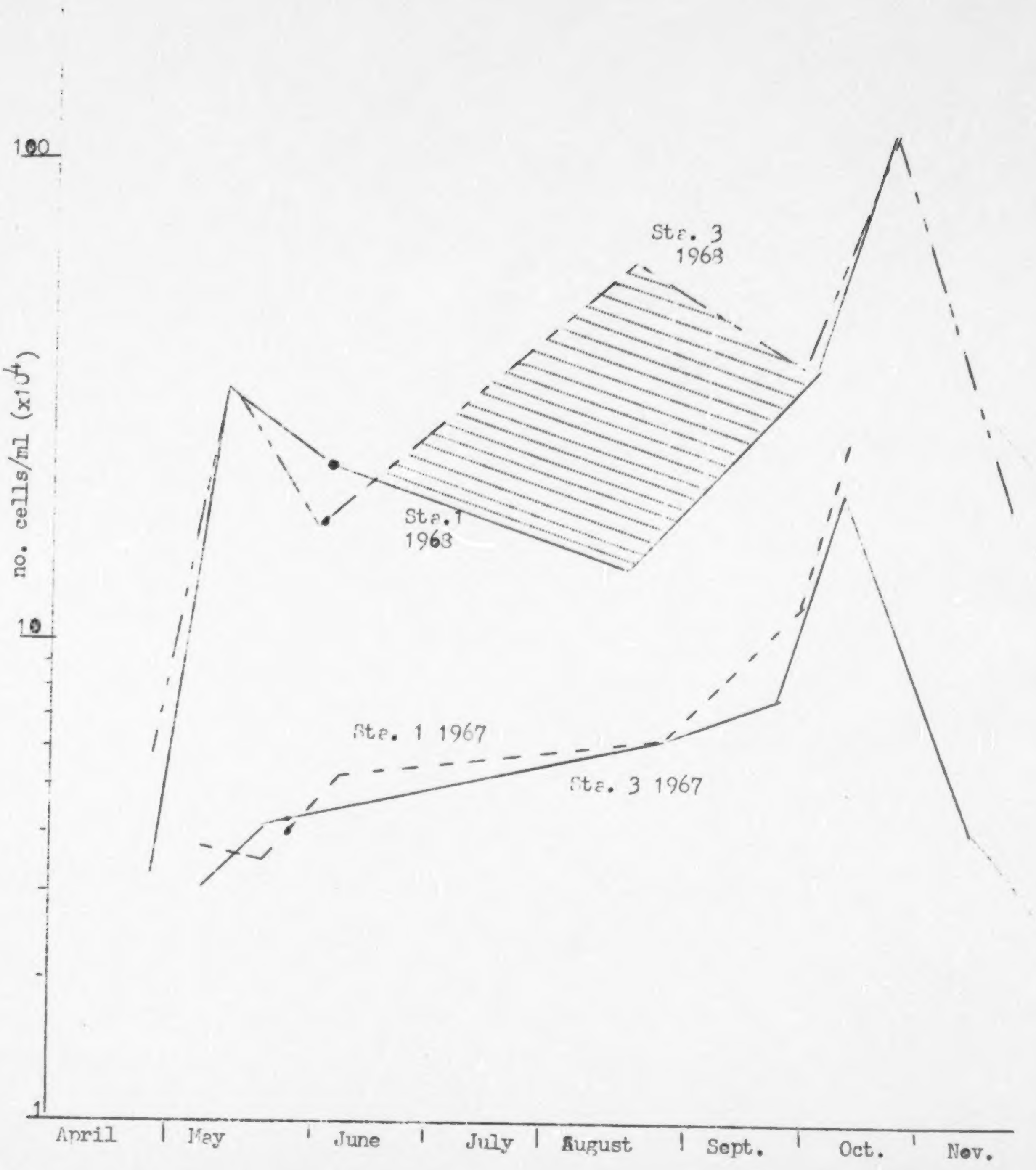


Figure 33B. Comparison of Stations 1 and 3 for 1967 and 1968 during periods of high thermal release.



no significant variation between the population of the two years. When the same ANOVA test was applied to the same sampling dates for Station 3 the hypothesis ($H:u_i=u_k$) was rejected at the 95% confidence level. This indicated that during the spring, summer and fall when ambient river and air temperatures were increasing or high the thermal effluent appears to have a significant effect at station 3. This confirms the observations of the actual samples and the deviations on the curves of Figs. 31 and 33A. Station 3 shows a large divergence (shaded portion) relative to Station 1 during 1968 which reached a magnitude of 4.3 times Station 1 during August. The curves for 1967 were almost identical.

The total quantitative data only depict the influence of temperature on the numbers of organisms. This tells nothing about the effect on the community species composition. To further the credibility of the quantitative data that thermal effluent was influencing the phytoplankton, plankton tows and phyco-periphyton were investigated. During the spring and summer of 1968 and the winter of 1969, plankton tows were made at stations 1, 3 and B (except during the winter of 1969 when plankton was towed at 1, 3, 6). Table 5 is a list of the species found and the stations from which they were recovered. Diatoms showed the largest numbers of individual species except in August 1968 when the green alga Scenedesmus quadricauda and the bluegree alga Microcystis aeruginosa bloomed. In order to assess the degree of floristic similarity between the stations on a given date numerical analyses were adopted. The Jaccard (63) Coefficient of Community (C.C.) was used as a measure of similarity between two stations. The equation is:

A = number of species common to two stations

B = total number of species at two stations

$$C.C. = \frac{A}{B} \times 100 \quad (1)$$

As a check on the C.C. analysis and to analyze the similarity between more than two stations the Koch (64) Index of Biotal Dispersity (I.B.D.) was used.

TABLE 5. Phytoplankton species collected by tows during thermal conditions.

Date	4-24-68			6-17-68			8-20-68			1-15-69		
Station	I	3	B	I	3	B	I	3	B	I	3	6
Species												
Bacillariophyta												
Achnanthes												
acares(?)										x		
lanceolata						x						
minutissima					x	x						
Amphora												
ovalis						x						
Asterionella												
formosa	x	x	x	x	x	x	x	x				
gracillima	x											
Biddulphia sp.	x											
Cocconeis												
diminuta		x										
placentula				x	x	x	x	x				
Coscinodiscus	x	x										
radiatus												
Cyclotella												
glomerata				x	x	x	x	x			x	x
meneghiniana					x	x	x	x				x
michiganiana										x		x
stillegra				x	x				x			
Cymbella												
lanceolata	x											
tumida		x										
turgida		x		x	x	x		x	x	x	x	x
ventricosa		x		x	x	x		x				
Cymatopleura sp.		x										
Diatoma												
anceps										x		
elongatum	x		x									
hiemale			x									
vulgare				x	x	x		x		x	x	x
Epithemia												
turgida				x								
Eunotia												
formica					x							
pectinalis			x	x								
pectinalis var. minor		x										
Fragilaria												
brevistriata				x		x					x	x
capucina	x		x									
construens	x	x	x			x						
crotonensis	x	x	x	x	x	x	x	x		x		
intermedia	x	x	x	x								
pinnata		x										
virescens		x										
Frustulia												
rhomboides				x	x		x		x			
rhomboides var. capitata				x		x					x	
rhomboides var. viridula							x					
Cocconeis												
pediculus											x	x

Gomphonema												
accuminatum	x					x					x	
constricta					x							
olivaceum		x	x							x		
parvulum				x	x	x					x	
parvulum var. micropus				x		x		x	x			
sphaerophorum						x						
Gyrosigma												
kutzingii				x							x	
Hannea												
arcus	x	x	x	x	x	x		x	x	x		x
Melosira												
ambigua		x		x		x	x	x				
crenulata	x	x	x	x	x	x						
distans	x	x	x									
granulata		x	x									
islandica	x	x	x	x	x	x	x	x		x	x	x
italica	x		x	x								
varians	x	x	x	x	x	x	x	x		x	x	x
Meridion												
circulare	x			x		x						
Navicula												
canalis	x											
confervacea(?)				x								
cryptocephala		x		x	x	x						
cuspidata		x										
exiqua		x			x							
gastrum		x	x									
hambergii						x						
odiosa							x	x				
protracta							x	x				
pupula var. mutsta(?)											x	
radiosa												x
secreta var. apiculata(?)										x		
viridula								x	x			
zanoni					x							
Nedium												
alpina(?)						x						
iridis(?)					x							
Nitzschia												
acicularis		x	x									
amphilia				x		x	x	x				
filiformis	x											
hungarica	x		x									
lorenziana		x										
palea		x		x	x	x		x	x	x		
paradoxa	x											
sigma	x											
Ophephora												
martyii		x										
Pinnularia												
rupestris		x	x									
sudetica(?)					x							
viridus				x								
viridus var. minor		x										
Rhizosolenia												
minima	x	x	x									

Rhoicosphenia												
curvata				x	x							
Stephanodiscus												
dubius												
Stauroneis												
anceps f. gracilis(?)					x							
phoenicentron					x							
Surirella												
ovalis	x	x	x									
ovata			x	x	x							
robusta			x					x	x			
Synedra												
actinastroides	x	x										
acus		x										
amphicephala(?)											x	
nana			x									
parasitica						x						
rumpens	x								x			
rumpens var. fragilarioides					x							
tabulata (?)		x										
ulna				x	x	x	x	x		x	x	x
ulna var. celna	x	x	x									
ulna var. oxyrhnchus	x				x	x	x	x				
ulna var. oxyrhnchus f. contracta				x								
vaucheriae	x	x										
Tabellaria												
fenestra				x	x							
flocculosa				x		x			x			
Chlorophtya												
Actinastrum												
hantzschii							x	x	x			
Characium												
stipitatum			x									
Chlamydomonas sp.			x									
Chlorella-like	x	x	x									
Chlorococcum humicola		x										
Closterium sp.	x	x	x									
Cosmarium sp.	x		x									
Desmiduim												
aptogonium (?)							x	x				
Euastrum sp.	x		x									
Endorina sp.		x										
Francela												
ovalis							x		x			
Kirchner obesa var. major							x		x			
Haematococcus												
lacustris	x											
Pediastrum												
boryanum			x									
duplex			x		x		x	x	x			
duplex var. gracillima					x	x	x	x	x	x	x	
Polyedriopsis												
spinulosa							x					
Scenedesmus												
bijuga							x	x	x			
quadricauda	x	x	x			x	x	x	x			

Staurostrum												
lacustre							x					
o'mearii(?)							x					
Stigeoclonium												
lubricum	x		x									
Ulothrix sp.	x		x									
Stichococcus												
subtilis			x									
Cyanophyta												
Anabaena												
circinalis							x	x	x			
Chroococcus												
dispersus	x	x	x									
dispersus var. minor				x	x	x	x	x	x	x	x	
minutus							x	x	x			
turgidus	x	x	x			x	x	x	x			
Hapalosiphon												
welwitschii												x
Lyngbya												
hieronymusii	x											
versicolor		x										
Microcystis												
aeruginosa							x	x	x	x		x
Oscillatoria												
angustissima						x	x	x	x			
limetica		x										
subbrevis												x
tenuis var. tergestina				x	x	x				x		
Flagellates												
Ceratium fusus			x									
Dinobryon												
lavaricum	x		x									
setularia	x	x	x									
Gymnodinium sp.	x	x										
Peridinum sp.			x									
Phacus sp.			x									
Synura												
uvella	x	x			x							

The equation is:

T = arithmetical sum of all the species found at each station.

S = total number of species at all stations

n-1 = degrees of freedom (number of stations minus 1)

$$\text{I.B.D.} = \frac{(T-S)/n-1}{S} \times 100 \quad (2)$$

The data derived from equations (1) and (2) are reported as a percent. The higher the number, the greater the similarity between the communities in the different sampling areas. Brown (71) reports that a value of 60-65% was the critical level for determining homogeneity in her plankton samples. However, she studied lakes and as yet no definitive work has been published to indicate this critical level of homogeneity for river plankton.

Equations (1) and (2) were applied to the species collections reported in Tables 5 and 6. Table 7 is a compilation of the floristic indices for the phytoplankton. Since certain species come and go and some are relatively scarce, the indices tend to be low except during the period of August 1968, when a bloom was underway and appeared to have increased the similarity of the floras between the stations. This is not unreasonable since successful bloom organisms tend to become dominant and a stable condition exists temporarily in the environment. This bloom and resultant stability allowed a better statistical comparison between the phyco-periphyton and phytoplankton.

Table 8 is a list of the floristic indices for the phyco-periphyton. The attached algae at station 1 (81° F) and in the thermal effluent (100° F) at station 3 were compared. Table 6 is a list of the species found on the collection surfaces of the phyco-periphyton sampler. No actual counts were made. This represents a microscopic observation based on the extensive quantity of cells of bluegreen algae noted and the very few viable (chloroplast containing) cells of diatoms present. In the thermal effluent the predominant algae were blue-greens. Large numbers of cells of the blue-green algae *Oscillatoria* and *Microcystis* were present at station 3 while at station 1

TABLE 6. Quantitative analysis of phycoperiphyton experimental data during the period July-October 1968.

Date	7-30-68		8-9-68	8-20-68			9-10-68			10-2-68	
Station	IT	3T	IT	IT	3T	3S	IT	3T	3S	IT	3T
Species											
BACILLARIOPHYTA											
Achnanthes											
deflexa (?)	x										
lanceolata	x			x		x	x		x	x	
lanceolata var. detia				x							
minutissima				x		x	x	x		x	
pergalia var. fossilis(?)								X			
Amphora											
ovalis	x							x			
Asterionella											
formosa	x	x	x	x	x	x				x	
Cocconeis											
pediculus				x							
placentula	x	x	x	x	x	x	x	x	x	x	x
Cyclotella											
glomerata		x		x	x		x	x	x	x	x
meneghenlana		x	x	x		x	x	x			x
michiganiana		x						x		x	x
stelligra				x		x					x
Cymbella											
affinis			x	x							
cistula			x								
turgida	x	x		x							
ventricosa	x							x	x	x	x
Diatoma											
elongatum										x	
heimale						x		x			
Eunotia											
pectinalis var. mior			x								
Epithemia											
turgida				x				x		x	x
Fragillaria											
brevistriata			x	x				x			
capucina											x
crotonensis	x	x			x	x	x		x	x	
intermedia								x			
leptostauron											x
pinnata			x								
Frustulia											
rhomboides var. capitata		x									
Gomphonema											
constrictum				x							
parvulum			x	x		x	x	x		x	x
parvulum var. micrpus		x									
Hannea											
arcus	x	x	x	x		x		x			x
Melosira											
ambigua	x						x				
islandica	x	x	x	x	x	x	x		x	x	x
italica	x				x						
varians	x	x	x	x	x	x	x	x	x	x	x

Meridion											
circulare									x		x
Navicula											
bacillum											x
capitata var. hungcirica	x										
cincta			x								
cryptocephala var. venter(?)	x										
delawarensis			x								
exigua	x	x									
gregaria	x	x	x			x					
minima						x					
mutica	x										
orbisculata(?)			x	x							
peregrina	x										
placentula(?)						x	x				
pupula var. capitata	x						x				x
venerabilis(?)					x		x			x	x
Nitzschia											
amphibia										x	x
amphora	x										
lorenziana										x	
palea	x	x	x	x	x						x
Rhoicosphenia											
curvata					x						
Stauroneis											
anceps	x	x	x								
phoenicentron											x
Stephanodicus											
dulius											x
Surirella											
ovata					x		x				
Synedra											
rumpens				x							
rumpens var. scotia									x		
ulna	x	x	x	x	x	x	x		x	x	x
ulna var. impressa			x								
ulna var. oxyrhynchus								x		x	x
Tabellaria											
fenestra			x	x		x		x		x	
flocculosa	x			x	x						
CYANOPHYTA											
Anabaena											
circinalis				x	x						
Aphanothece											
microscopica	x					x					
Chroococcus											
dispersus var. minor				x	x		x	x		x	x
turgidus		x								x	
Dactylococcopsis				x							
smithii				x			x	x	x	x	x
Hapalosiphon											
intricata							x		x	x	
Merismopedia											
convoluta						x					

Microcystis											
aeruginosa					x	x	x	x	x	x	x
Oscillatoria											
angusta	x	x		x		x	x	x		x	
splendida	x										
tenuis var. tergestina					x	x		x			
Pseudcinabaena											
schmidlei	x										
Stigonema											
turfaceum										x	
CHLOROPHYTA											
Actinastrum											
gracilimum					x	x					
Chlorella											
vulgaris											x
Oedogonium											
epiphyticum(?)										x	
Pediastrum											
duplex var. gracillimum	x				x			x			
Scenedesmus											
quadricauda	x				x						
Schizomeris											
leiblemii								x			
Spirogyra sp.								x		x	
Tetraidron											
trigonium var. gracile			x								
Ulothrix											
variabilis							x	x	x	x	
Grand Total	31	19	23	29	21	22	23	26	14	29	28

The symbol T = Top 1/2 meter of water.
S = slide shifted from station 1 into thermal effluent.

TABLE 7. Analysis of phytoplankton using the Jaccard Coefficient of Community (C.C.) and the Koch Index of Biotal Dispersity (I.B.D.).

Date	C.C.-1	C.C.-2	C.C.-3	I.B.D.
4-24-68	34.7	43.9	38.7	39.1
6-17-68	40.7	48.1	39.3	34.1
8-20-68	62.5	34.1	43.6	52.3
1-15-69	25.9	31.0	33.3	31.8

C.C.-1 = Station 1 vs. 3

C.C.-2 = Station 1 vs. B (Station 6 substituted for B on 1-15-69)

C.C.-3 = Station 3 vs. B (Station 6 substituted for B on 1-15-69)

TABLE 8. Analysis of phycoperiphyton using the Jaccard Coefficient of Community (C.C.) and the Koch Index of Biotal Dispersity (I.B.D.).

Date	C.C.-1	C.C.-2	C.C.-3	I.B.D.
7-30-68	35.1	--	--	35.1
8-20-68	39.3	37.8	26.5	43.2
9-10-68	30.6	45.8	21.9	32.9
10-2-68	35.7	--	--	35.7

C.C.-1 = Station 1 vs. 3

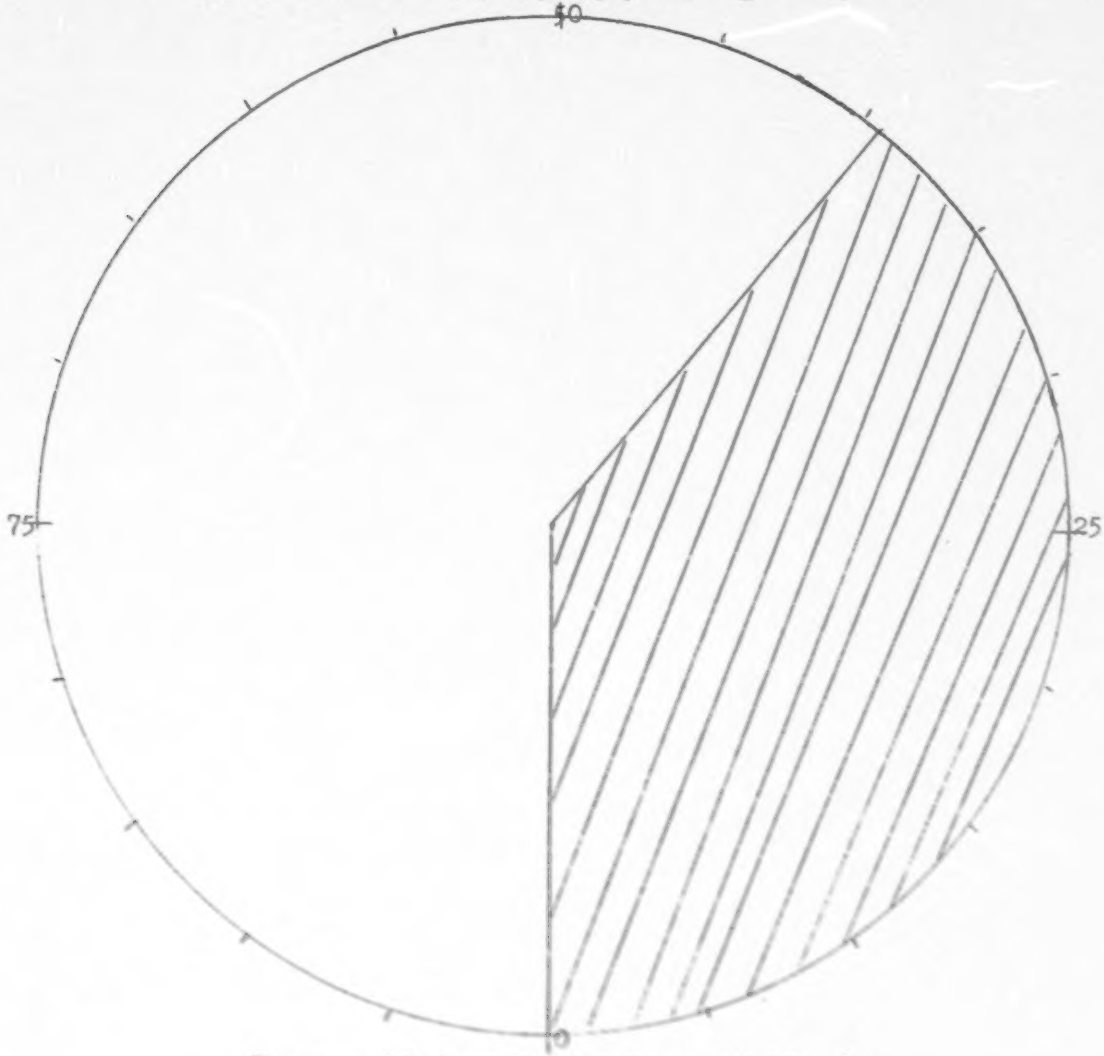
C.C.-2 = Station 1 vs. 3T (Transfered from station 1 on 8-9-68).

C.C.-3 = Station 3 vs. 3T

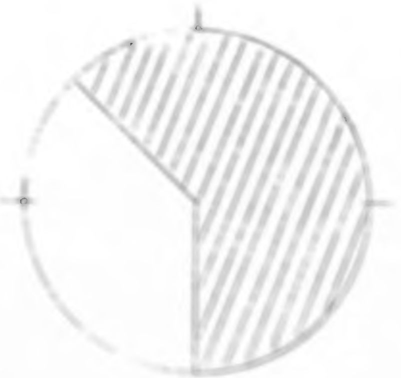
diatoms were dominant. It was noted that most of the diatom frustules on the sampler at station 3 had no chloroplasts or visible cytoplasm. Since it was difficult to tell whether the empty diatom frustules at station 3 were the result of heat kill or other conditions, slides were transferred from station I to station 3, allowed to remain for 2 and 6 weeks respectively, and recovered. The original healthy-looking chloroplast-filled frustules were generally empty and blue-green algae and green algae had replaced the diatoms. A few resistant diatom forms such as *Melosira islandica*, *M. varians*, *Nitzschia palea*, *Hannea arcus*, *Cocconeis placentula*, and *Fragilaria crotonensis* were the most dominant. These successional observations are not revealed by the various mathematical analyses. The mathematics only report the occurrence of an anomaly. The analysis of the actual species shows that shifts in community structure occur in relation to temperature. Fig. 34 is designed to compare the data during the bloom in August 1968. The phytoplankton floristic similarity between station I and 3 was very similar. The phyco-periphyton for the same date is not as similar. The bloom was composed of forms that can thrive in elevated (above ambient) temperature conditions. The attached forms were not alike with the loss of many diatoms. Fig. 34 was intended to show that even though river plankton communities at station I and 3 were very similar, the attached algae were significantly different indicating a temperature influence. Similar data are reported (68, 70) for the periphyton community.

In comparing the above results to previous reports (67,69) on the lack of significant effect on the algae as a result of thermal discharges, this study presents what may be definite effects of the thermal discharge. Mathematically, heated effluent represents a stimulatory agent. Thermal addition appears to effect a shift in the population structure in terms of species encountered. This was most apparent for phyco-periphyton where there was a shift from a diatom-dominated community at station I to a blue-green dominated community at station 3. This dominance is in terms of the large numbers of

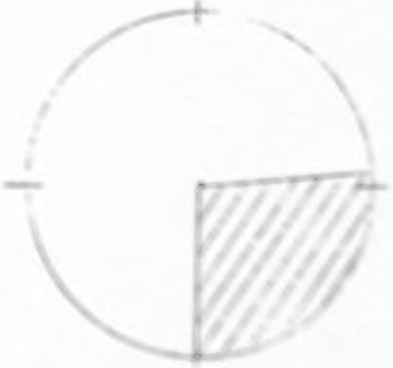
Figure 34. Comparison of the Coefficient of Community between phytoplankton and phyco-periphyton; August 20, 1968.



Phyco-periphyton; Station 1 v.s. Station 3.



Phytoplankton; Station 1 v.s. 3



Phyco-periphyton; Station 1 v.s. 3 of slide shifted on 8-8-68 healthy blue-green algal cells apparent when identifying the phyco-periphyton slides. This shift in dominance agrees with other observations (68,72). From a morphological standpoint, the increase in the number of eight-celled coenobes of Scenedesmus quadricauda and the apparent reduction in size of the many diatoms and green algae in the heated effluent agrees with others (70).

In conclusion, the CYAPC plant at Haddam Neck, Connecticut, has had a measureable effect on Connecticut River phytoplankton in the area from station 3 to station 6. How far reaching and profound this effect will be depends on the volume of flow, the position of the tide, and the air temperature. At low river flow, high flooding tide and high air temperatures, the heated effluent tends to be retained longer in the area above and below station 3. The longer the retention time the higher the probability of a greater effect on the biota.

How important many of the subtle effects will be in the future to the ecosystem economy of the river below the area of thermal discharge is difficult to predict for the aquatic food web. It can be projected that two factors will be most imporant. First, to primary consumers the shift from a diatom dominated community to a blue-green dominated community may eliminate many consumer spcies because of the indigestibility of the blue-green algae. The secnd effect, significant to bottom feeders, but which was not directly meaured, was the change in density of the water as a result of heating. Increasd temperature decreases the density and many of the sediments will settle ut in the area of the thermal outfall. The settling out may cover biologically productive areas, reducing the overall productivity of that portin of the river.

A zone of effect and recovery is noted in the river from station 3 to station 6. As long as onl one power plant is located in the area, and the flow characteristics of the river are not drastically altered, then it is reasonable to predict that the measureable thermal effects will not extend beyond this recovery area. The data does present an economic case for not locating industries and other utilities that use large quantities of cooling water near one another. Since thermal effluents stimulate the growth of algae, the cost of cleaning and maintaining intake facilities and heat transfer equipment may increase if water for cooling is used by industries downstream from areas of thermal discharges.

Finally, it has been noted that a tremendous increase in phytoplankton numbers has occurred over the study period. Such a concentration is very oxygen demanding on the waters in sloughs and pools of rivers and may contribute to adverse and lethal effects on the fauna during the night or periods of prolonged overcast. The respiring plants could remove dissolved oxygen and contribute to fish kills. The power plant by being a stimulator of the algal growth contributes to this phenomena. Also, by stimulating blue-green algal growth the possibility of developing toxic forms (73) increases. Thus, we consider the nuclear plant as an additive influence on phytoplankton ecology together with increased nutrient levels. Its effect at present cannot be estimated quantitatively or qualitatively on the general ecology of the Connecticut River outside of the immediate outfall area. However, the constant presence of warmed water together with the natural increase in plant nutrients may represent another stimulatory factor with eventual ecological emergence in terms of recurring critical dissolved oxygen levels.

4. Macrobenthic Invertebrate Populations

Results from a preliminary survey of the Haddam Neck section of the Connecticut River (74) showed a varied benthic population: chironomid larvae, oligochaetes, amphipods, isopods and small molluscs. The River bottom supported large numbers of individuals, but relatively few species. Quantitative and qualitative data were based on Petersen grab (dredge) samples collected from an 0.6 sq. ft. surface of the bottom. The same techniques were used through the present study. While one Petersen sample per station cannot be construed as representing accurately an enviornmental complex, a general trend was observed that seems to have justified the procedure.

The need for long range studies on any ecosystem is well exemplified by this study. A conclusion based on the data of one given year may seem to be negated by those of the succeeding year. In our 1967 final report we noted that a steady decrease in abundance of benthic invertebrates occurred during summer and early fall and fell to zero by 18 July 1967. Using the same sampling technique throughout, the reverse appears to be true this year, with the highest numbers found with the highest sediment temperatures from July 9 through August 2. However, this seeming contradiction may reflect but a shift seasonally. Relatively few organisms were found in the spring, with none collected in June 1969. Calendar months, as such, therefore should not be used as "time markers" for seasonal occurrence and abundance of organisms. Periods, involving more than one month, are more indicative of seasonal events.

Using this latter criterion, it appears that a natural diminution of numbers of organisms occurs in late spring and early summer. This phenonomon is accompanied by an increase of sediment temperature. It is not possible to correlate these two sets of data without including reproductive events within the benthic community. A lag of a month or more in the upswing of members may change with yearly variations in environmental factors; in this case, temperature. This, in time, will affect not only reproductive rates but also availability of nutrients for growth and development.

All of this must be kept in mind when considering the effect of thermal effluent on the natural environment. From about November 1968 through February 1969, sediment temperature at Station 3, the outfall, remained considerably higher than that of 1 and 8. Few to no animals were collected at 3 during this period. On the other hand, numbers increased to a high in February at the other two stations during this same period.

All of the above indicates that numbers of benthic animals do decrease with an increase in sediment temperature. An increase of temperature due to thermal effluent, with subsequent loss of organisms appears to corroborate this conclusion. Just what part of the ecosystem (life cycle, nutrients, metabolism, etc.) is affected is unknown at this time. Laboratory experiments are needed to determine this effect.

Station B, well below the power plant, seems to be the least affected, if at all, by thermal effluent. Results justify our earlier conclusion that this station can be used as a control for monitoring Station 3.

One other observation should be noted. Very few organisms are found in the channel where Stations I and B are located. Yet, many are found along the flats on either side. It would seem that constant scouring by boat and ship wash prevents development of extensive channel communities. Station 3, on the other hand, is right at the exit of the power plant cooling canal, essentially on a flat. In spite of this, the above conclusion seems to remain valid.

5. Bacteria - Quantitative

We should emphasize that, in all of our studies, we have not considered the autotrophic bacteria, some of which are primary producers and many of which are significant in biogeochemical cycles (e.g. sulfur) and subsequent ecosystem modifications. Similarly, we have not studied the incidence of pathogenesis which is important in some areas (75) or the occurrence of natural antibiosis in ecosystems.

Our work has concentrated on some heterotrophic saprophytic bacteria found in the Connecticut River. These organisms are considered usually as "transformers" in the environment by reducing high molecular weight organic compounds to simple, inorganic salts (NO_2, NO_3, NH_4, PO_4, etc.) which are then assimilated by the photoautotrophic primary producers (phytoplankton).

Considering the variety of organic compounds which a natural body of water may receive, either through the normal processes of run-off or by means of artificial addition in the form of industrial, agricultural and domestic wastes, both the numbers and types of bacteria present are important. Organic enrichment may range from simple sugars and amino acids which are utilized by most heterotrophic bacteria to the more complex carbohydrates (i.e. cellulose, starch, chitin), proteins and lipids. Also, the advent of routine use in agriculture of pesticides and exotic detergents in households has resulted in a pool of molecules which may require quite specialized micro-organisms to effect mineralization.

The presence of bacteria in rivers has been considered in general from two aspects; (1) as indicators of specific industrial pollutants (sulfur, iron, etc.) or sewage and therefore yardsticks of water quality for special use and (2) as indirect factors in oxygen consumption studies such as BOD values. Since the vast majority of bacteria found in rivers are derived from allochthonous (outside) sources such as soil or sewage, it may be of only academic interest to study the genera and species present under normal circumstances. However, in this study we are concerned with a concentrated environmental factor (heat) and it is therefore of more than passing interest to note the possible selection of specific metabolic groups as a function of thermal effluent. If this selection occurs, then the biochemical potential of the river under thermal influence may change by the elimination or increase of certain mineralizing types. Thus, of particular importance in the thermal area as opposed to the non-affected parts of the river are (1) the amount of self-purification, (2) rate of self-purification and (3) specific elimination of certain members of the biomass. Additional concepts on these ideas are available (76-78). While our studies were not designed primarily to determine the removal of dissolved, chemically defined compounds from the water by the metabolic activity of bacteria, the observations below may shed some light on the qualitative and quantitative effect of a "misplaced resource" on various components of river microflora.

a. "Total counts" - mesophiles

Bacterial populations at Stations 1, 3 and B during both prethermal and thermal periods are shown in Figs. 35-40. During the four year period counts varied randomly from a low of 1000/ml to a maximum of 250,000/ml. There was no evidence of pronounced seasonal effects and no significant differences were noted in counts before and after plant operation. Station 3 (outfall) did not show any meaningful variations when compared to counts at the other stations.

In general, bacterial numbers were lowest during 1965-1966 which was a drought period; conversely, counts rose during 1967 which was an unusually wet year.

b. Specific groups

i. Amylolytic. Bacteria capable of hydrolyzing starch were present in the River throughout the study period. Numbers fluctuated from a low of 100/ml to a high of 37,000/ml. There were no obvious variations between seasons or between prethermal and thermal periods. Lowest counts were recorded in 1965-66 followed by an increase in 1967 to 6000-8000/ml and a slight drop-off to about 4000/ml during 1968-69. These observations probably reflect climatic factors noted above. Numbers of amylolytic bacteria at all stations were similar; thermal effluent had no noticeable effect on numbers of these organisms.

ii. Lipolytic. Fat hydrolyzing bacteria varied from a low of 90/ml to a maximum of 5000/ml during the sampling period. There was no evidence of seasonal, thermal or location effect except that counts during the drought summer and fall of 1966 (600/ml) were all below the mean for the entire study.

iii. Proteolytic and acid and base producing bacteria. These groups were present throughout our study. The latter two showed summer minima

Figure 35. Mesophiles. no./ml: Station 1. Prethermal Period.

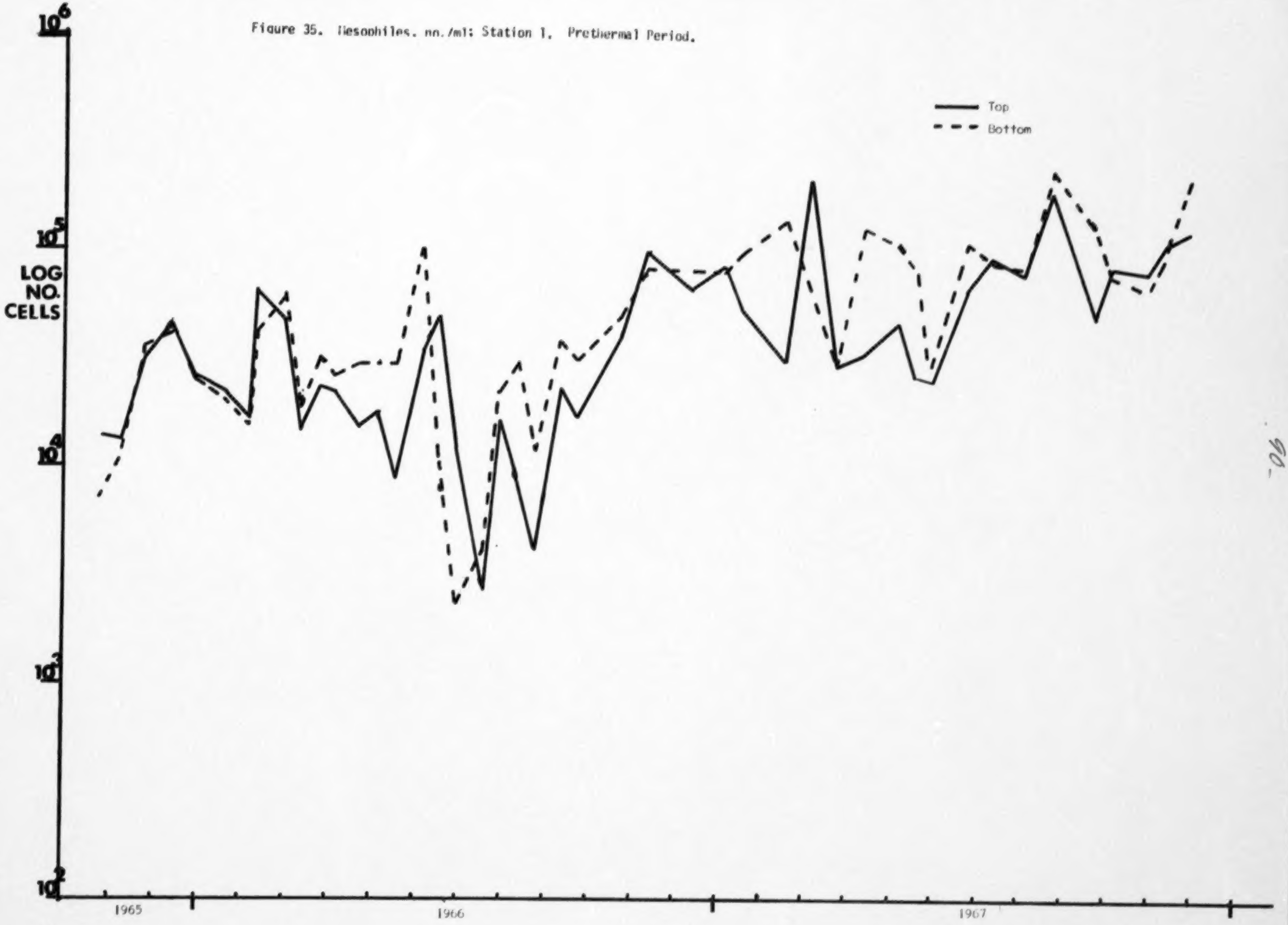
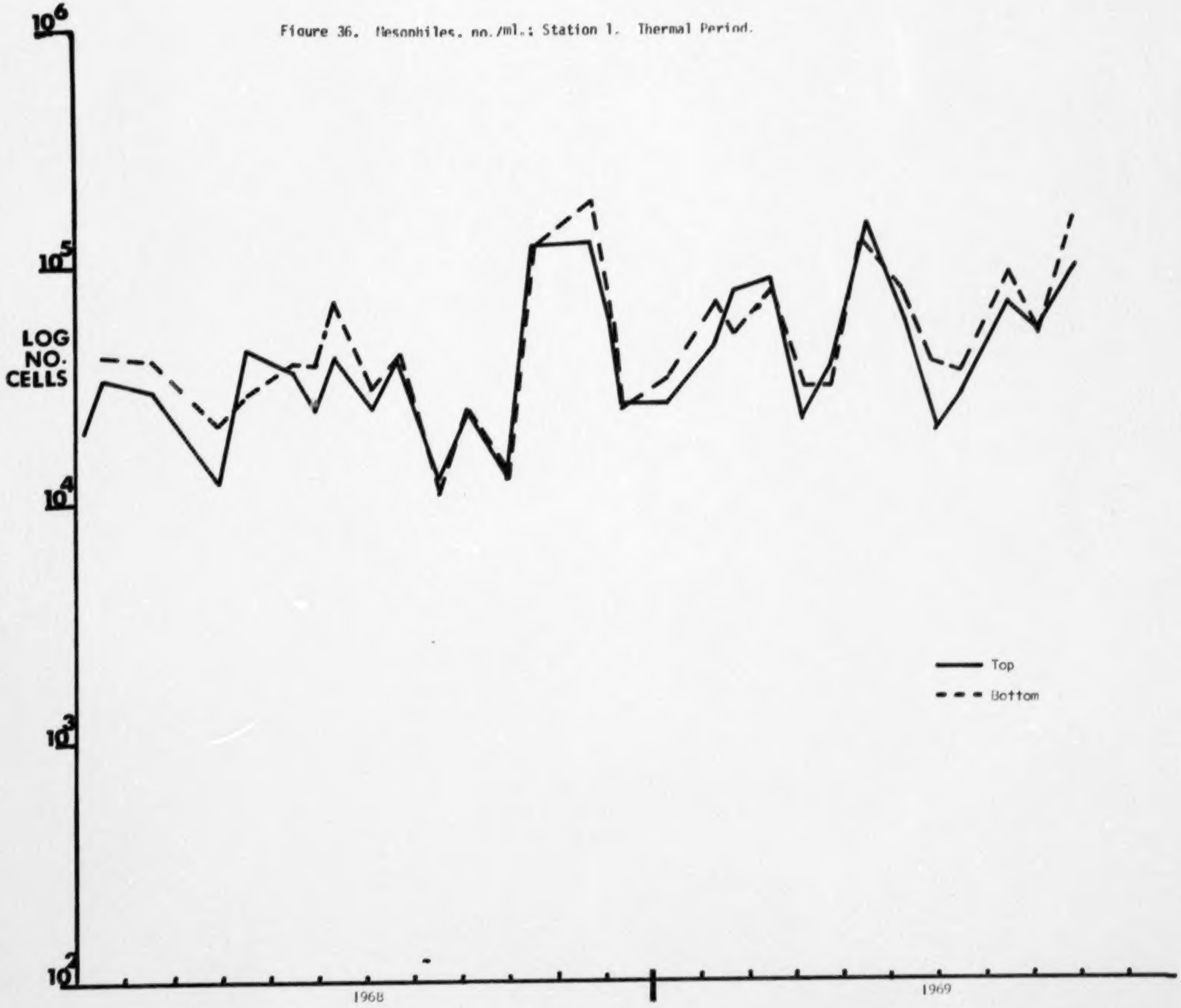


Figure 36. Mesophiles, no./ml.: Station 1. Thermal Period.



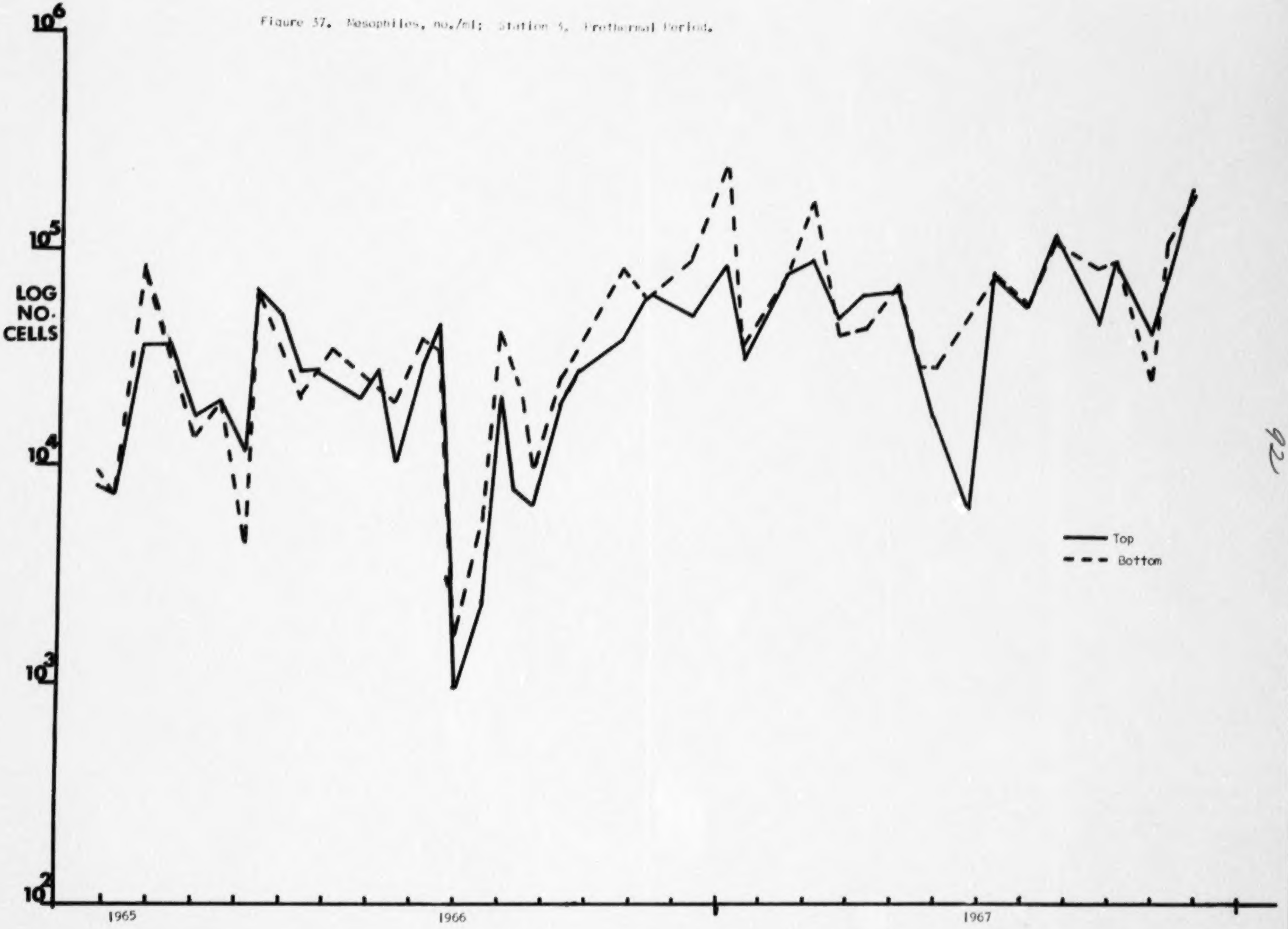


Figure 37. Mesophiles, no./ml; Station 5, Prethermal Period.

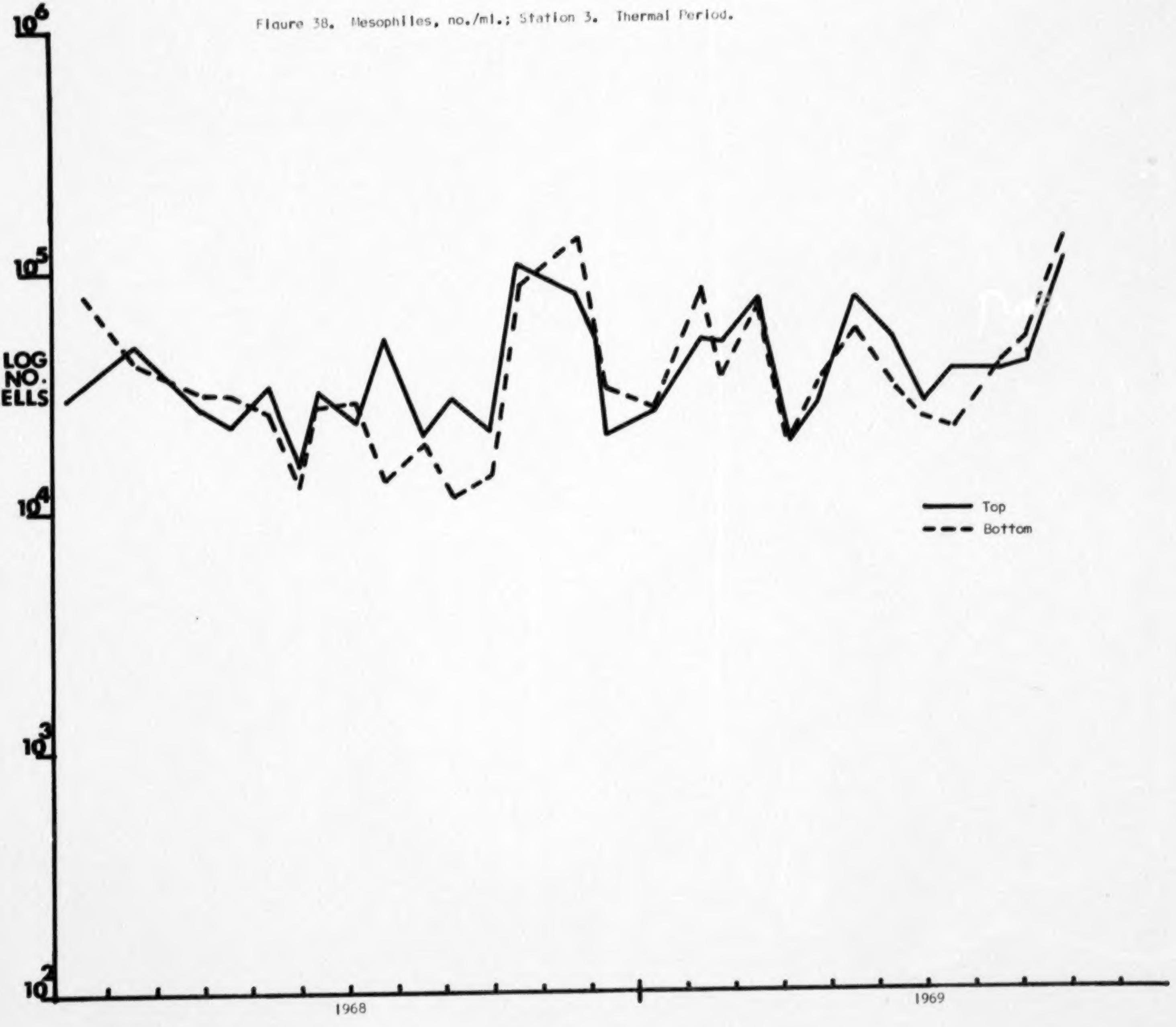


Figure 38. Mesophiles, no./ml.; Station 3. Thermal Period.

Figure 39. Mesophiles, no./ml.; Stations 7 & 8. Prethermal Period.

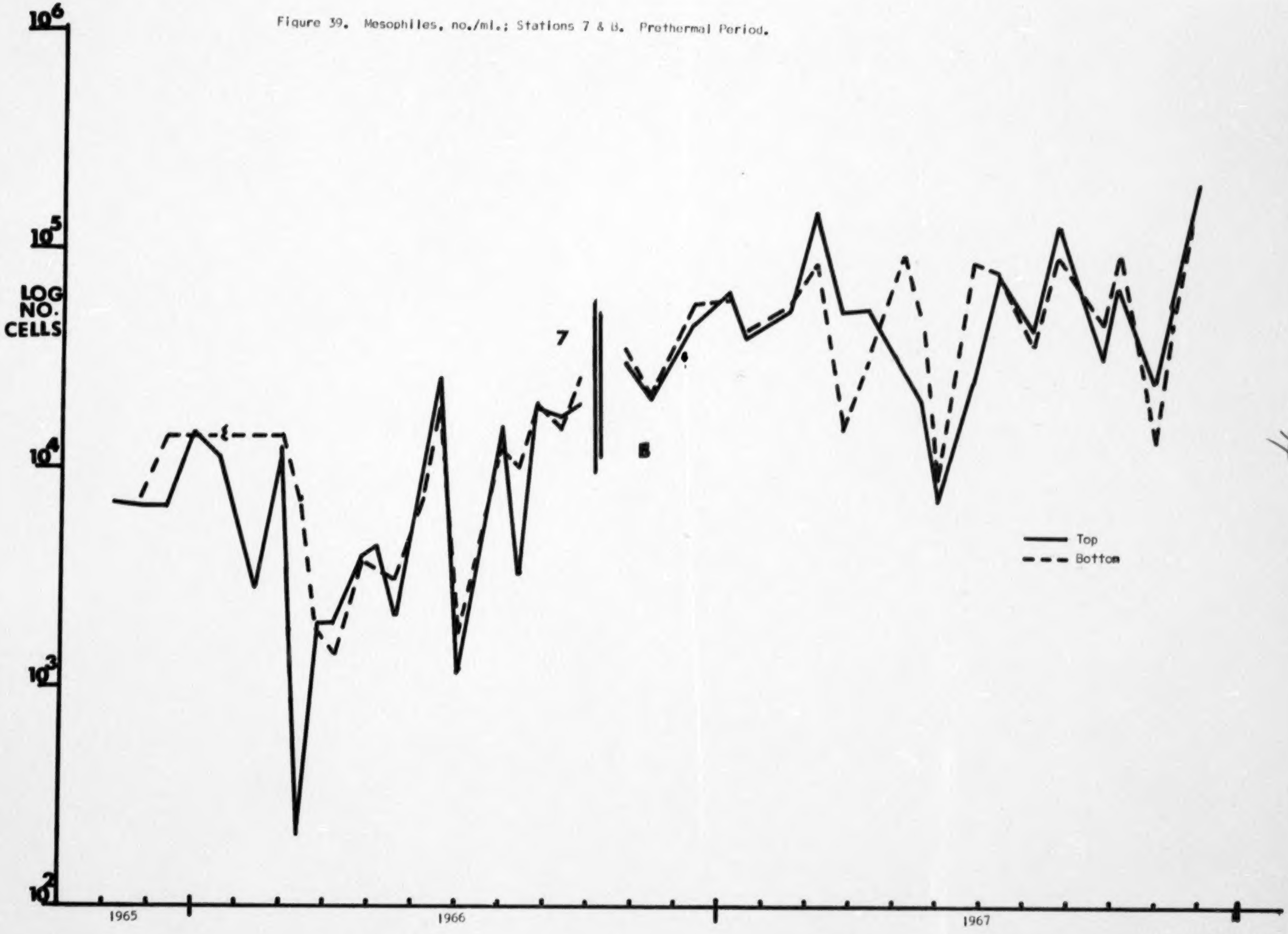
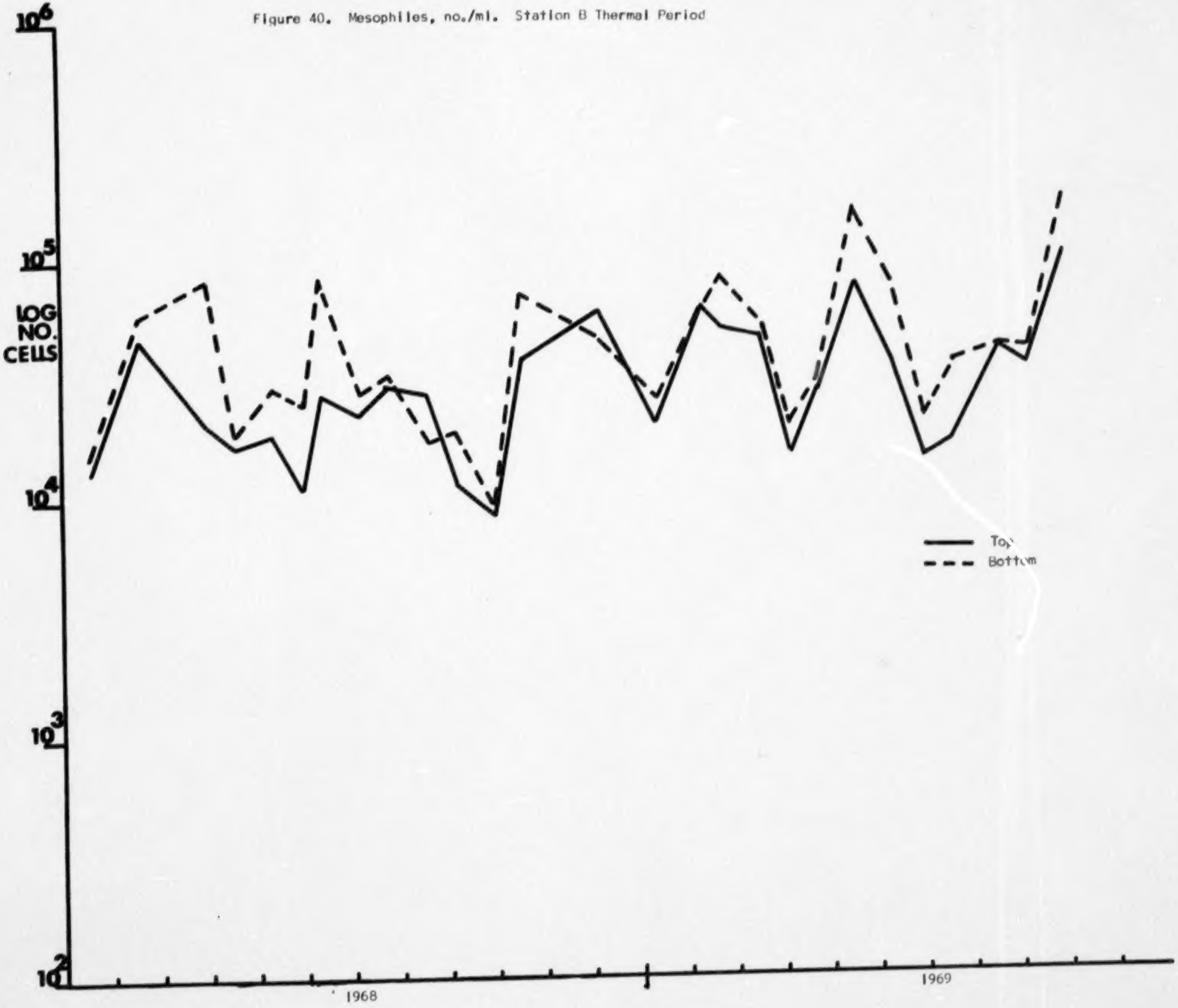


Figure 40. Mesophiles, no./ml. Station B Thermal Period



except during the rainy summer of 1967. Protein hydrolyzing organisms ranged from 300 to 8,100/ml while acid and base producing forms were present in smaller numbers; 10 to 1800/ml. As above, no differences were noted between stations as a function of plant activity.

The presence of groups i-iii above is perhaps more significant than their absolute numbers. A variety of carbohydrate, lipid and protein substrates are expected in any natural body of water which is contiguous with population densities and agriculture. While we have no measure of BOD requirements of the Connecticut River, it would seem from D.O. data and counts of specific groups of bacteria that the River is microbiologically capable of at least minimal mineralization of the present organic load since a wide variety of heterotrophic bacteria are present. In all cases, highest numbers of proteolytic, amylolytic and lipolytic bacteria in the River were related to greatest stream flows. We have not detected any direct quantitative or qualitative effect of thermal effluent on the distribution or occurrence of any of these organisms in the main body of the River or even at the outfall area.

iv. "Marine" bacteria. Bacteria capable of growth on a full strength seawater medium varied from 300 to 55,000/ml. A definite trend in populations was noted, with lowest counts routinely recorded during the summer and early fall and highest numbers found during the coldest portions of the winter. These trends were shown at all four stations, both before and after initiation of plant operation.

The strict psychrophilic nature of marine bacteria has been noted (79) as well as their capability of adapting to varying ion concentrations (80). If marine forms are entering the River from Long Island Sound on flood tides, we may have been detecting these bacteria in our samples as a function of seasonal River temperatures.

v. Psychrophiles. Bacteria capable of growth at 5° C showed an extreme reduction in numbers during the warm months of the year, ranging from a maximum of almost 4×10^6/ml in the cold months to a low of <10/ml in the summer (Figs. 41-46). This general pattern was evident throughout the four year study period and showed no deviation as a function of station location or plant activity.

Since psychrophile counts at Station 3 were not significantly different than counts at the other stations, several comments may be made. Firstly, bacteria in any of samplings may have had a very short residence time in that area; too short to allow a lethal effect of increased temperature. Secondly, the zone of mixing at Station 3 may be confined to the immediate outfall area and our sampling site was too far out to allow us to detect a loss of psychrophile populations if it did occur. Lastly, the observations below indicate that our "psychrophile" isolates are, in fact, capable of growth over a comparatively wide temperature range and may be classed as facultative psychrophiles.

vi. Thermophiles. Counts of bacteria growing at 45° and/or 55° C ranged from <10/ml to a high of 6,000/ml. These organisms demonstrated a cyclical pattern of seasonal distribution very similar to that shown above for psychrophiles; i.e., highest counts recorded during the winter months and lowest numbers observed in the summer (Figs. 47-52). Occasional microscopic examination of cultures selected for laboratory studies revealed the frequent occurrence of spore-forming bacilli, indicative of the genus *Bacillus* which are characteristically resistant to adverse conditions, including elevated temperatures. Also, many species are obligately thermophilic. *Bacillus* species are common inhabitants of soil and therefore may be more prevalent during periods of winter precipitation and run-off. Data developed below indicated that, in general, species of *Bacillus* were isolated most commonly during winter months which substantiates quantitative observations.

Figure 41. Psychrophiles, no./ml.; Station 1. Prethermal Period.

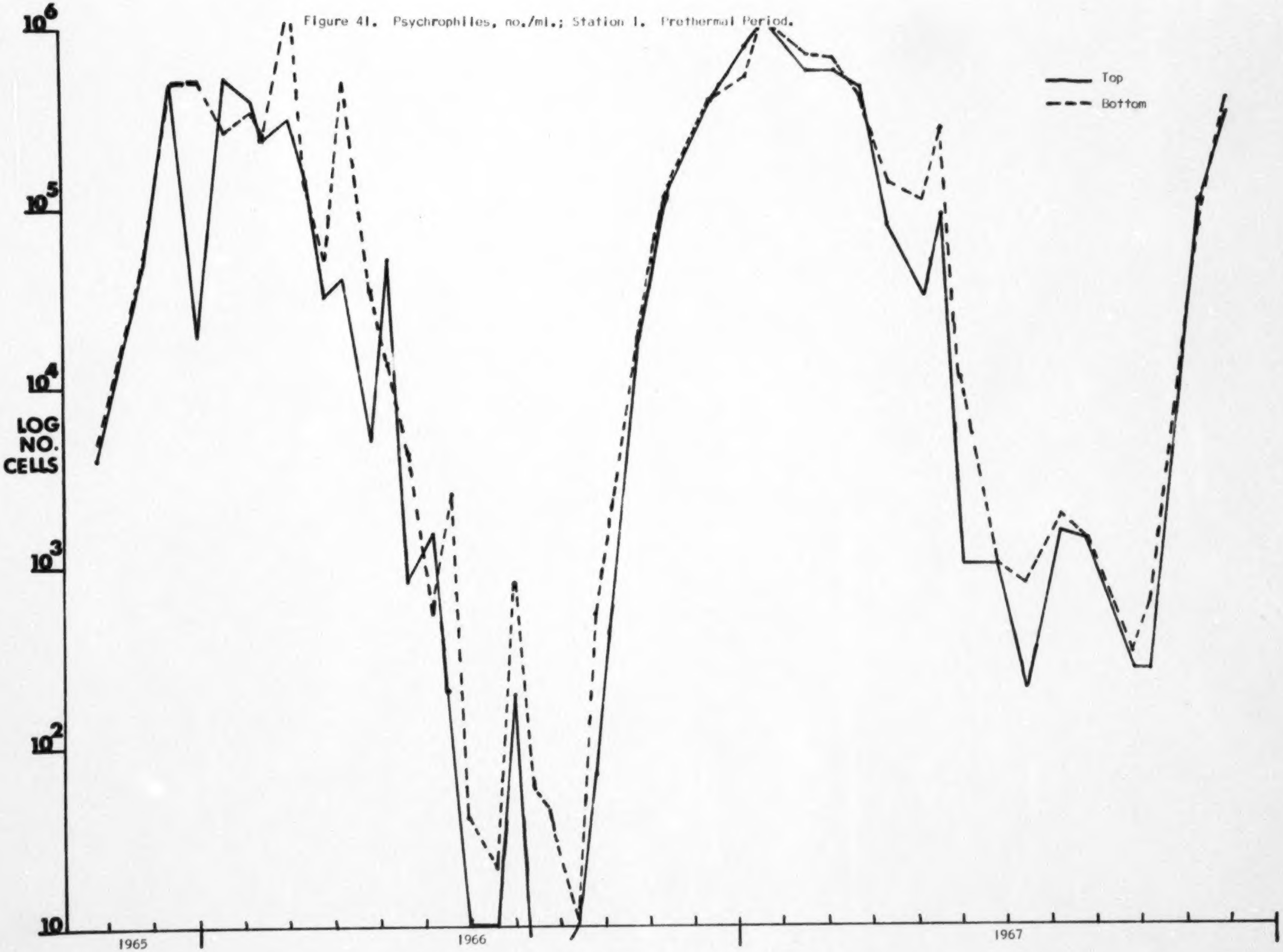


Figure 42. Psychrophiles, no./ml.; Station I. Thermal Period.

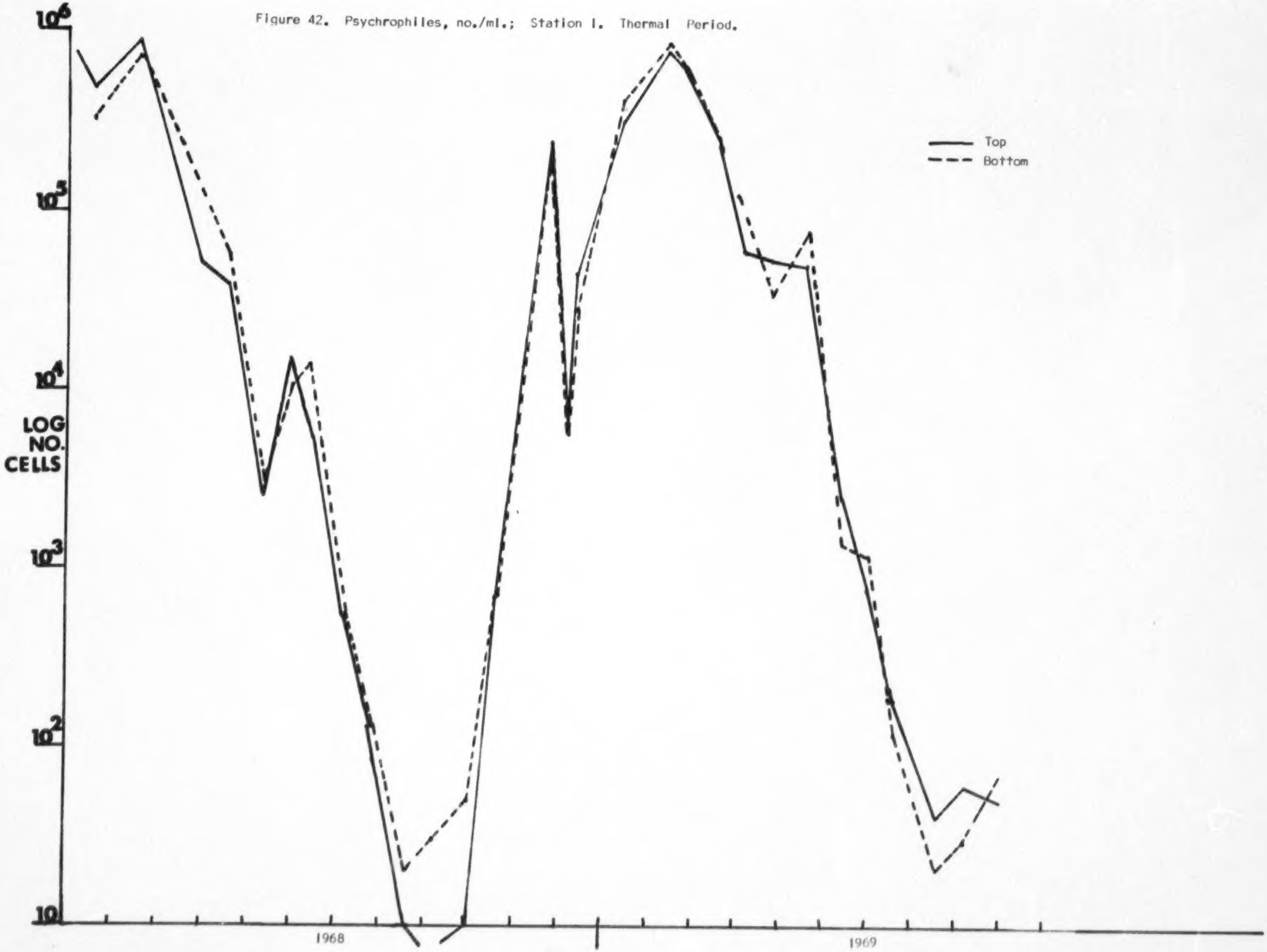


Figure 43. Psychrophiles, no./ml.; Station 3. Prethermal Period.

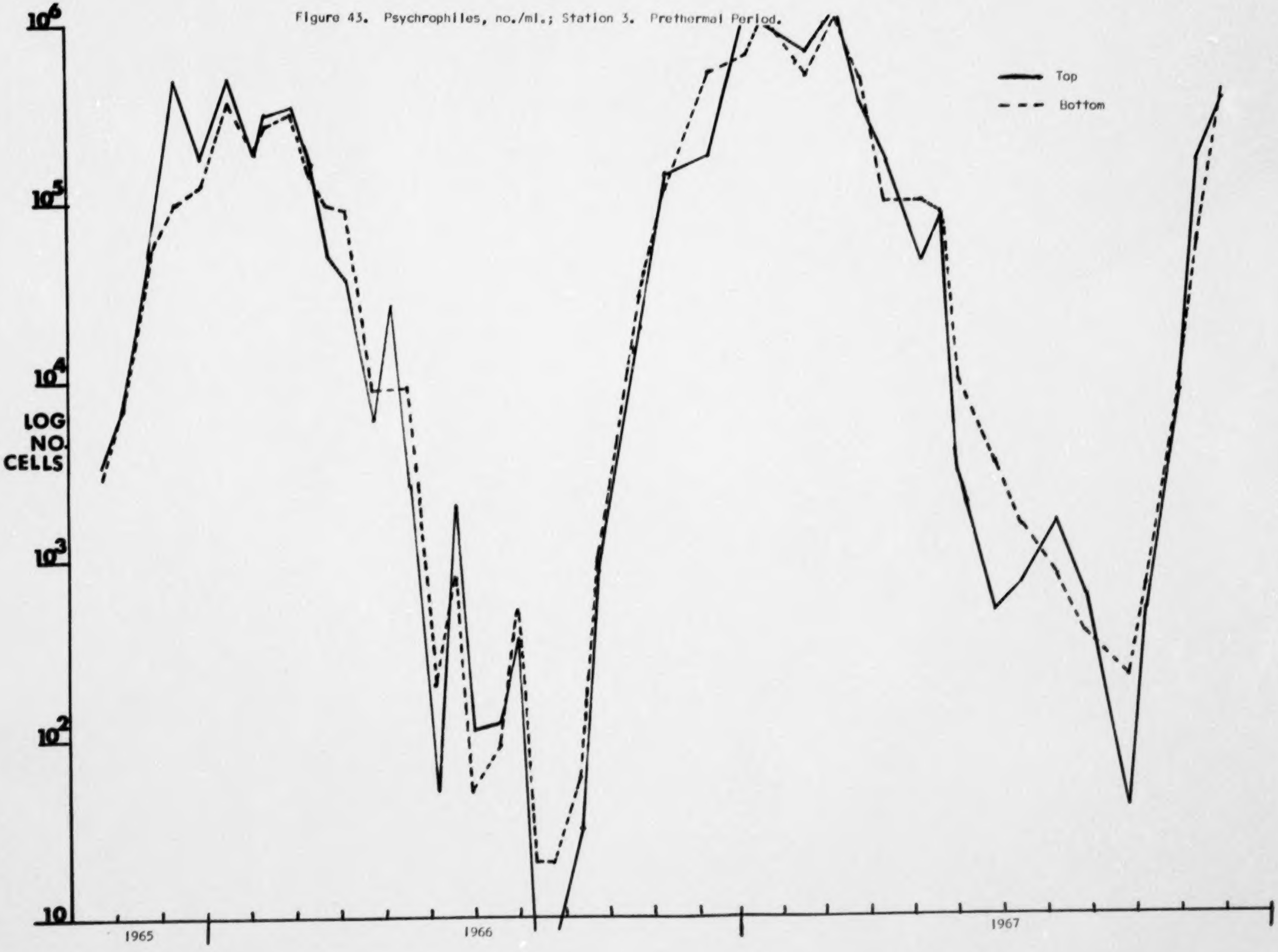


Figure 44. Psychrophiles, no./ml.; Station 3. Thermal Period.

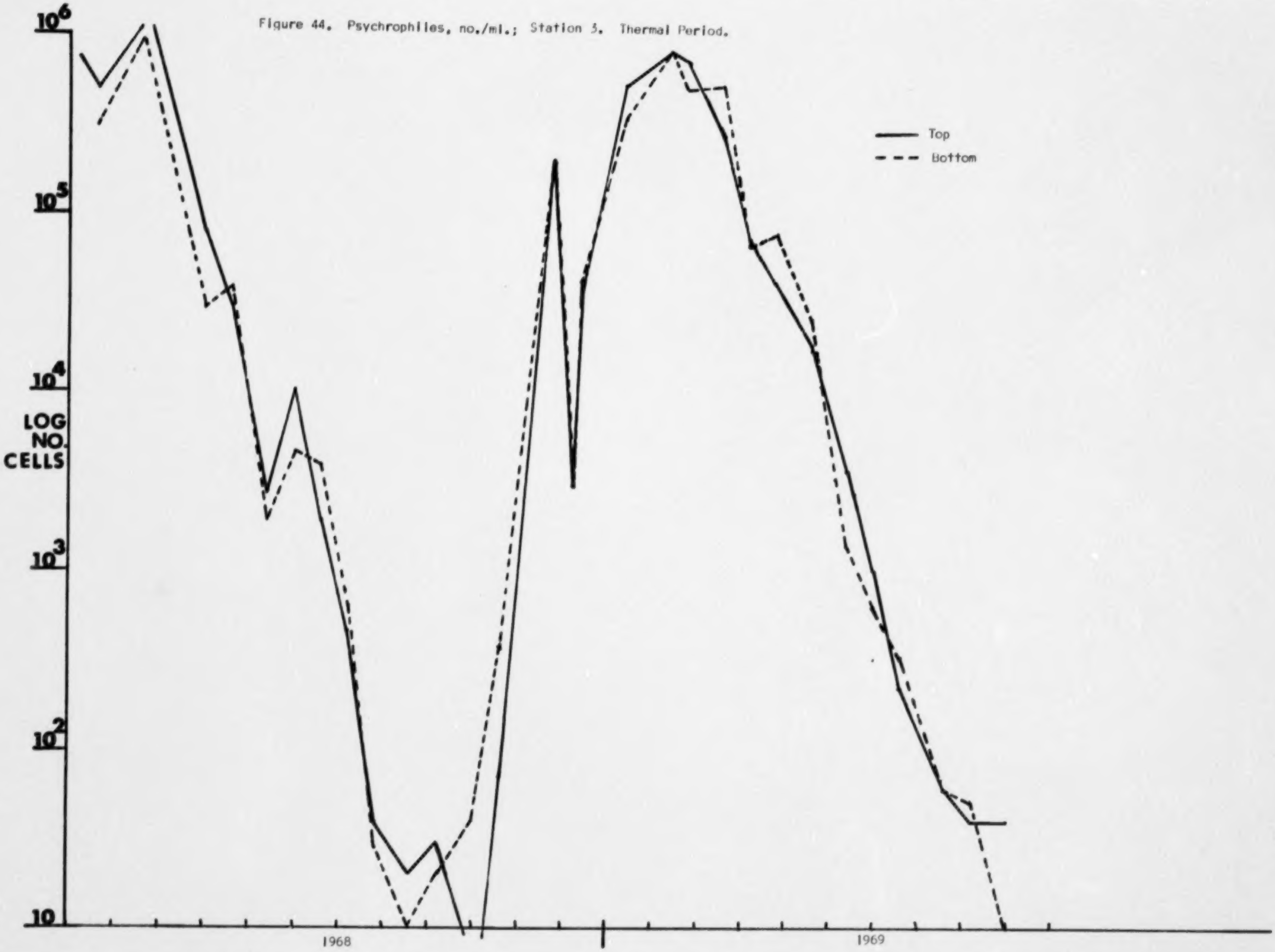


Figure 45. Psychrophiles, no/ml; Stations 7 & B. Prethermal Period.

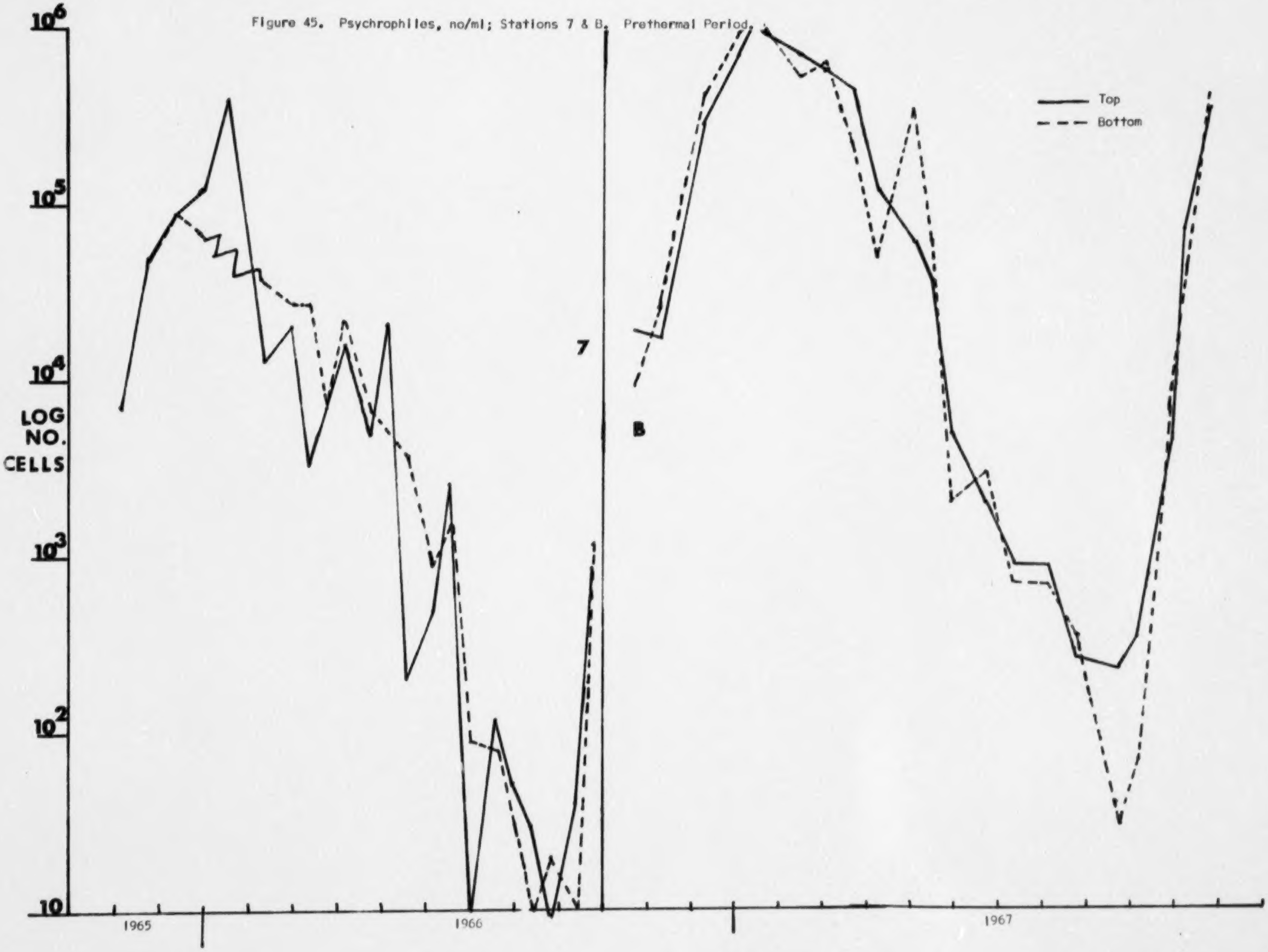


Figure 46. Psychrophiles, no/ml Station B. Thermal Period.

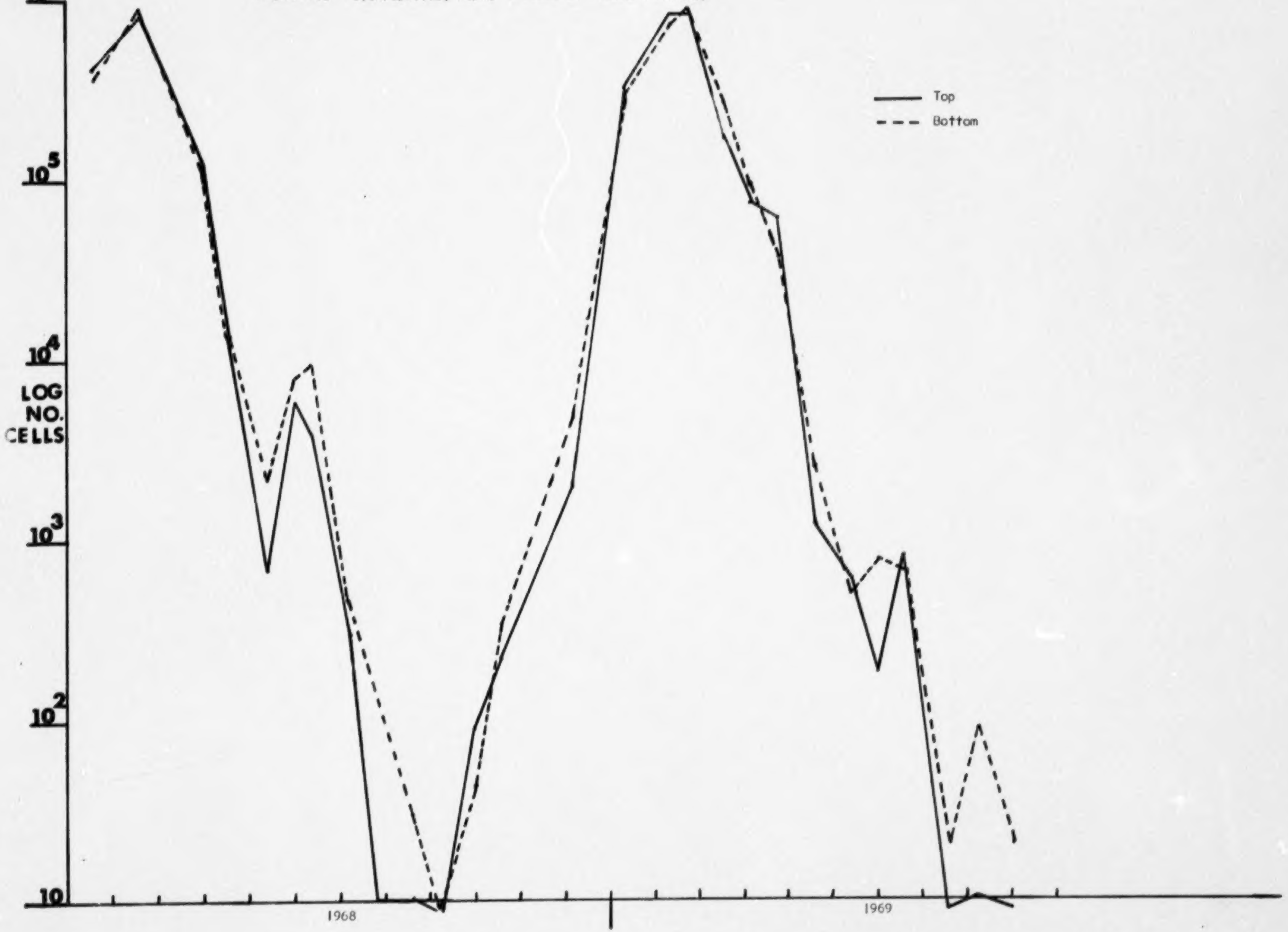


Figure 47. Thermophiles, no/ml Station I. Prethermal Period.

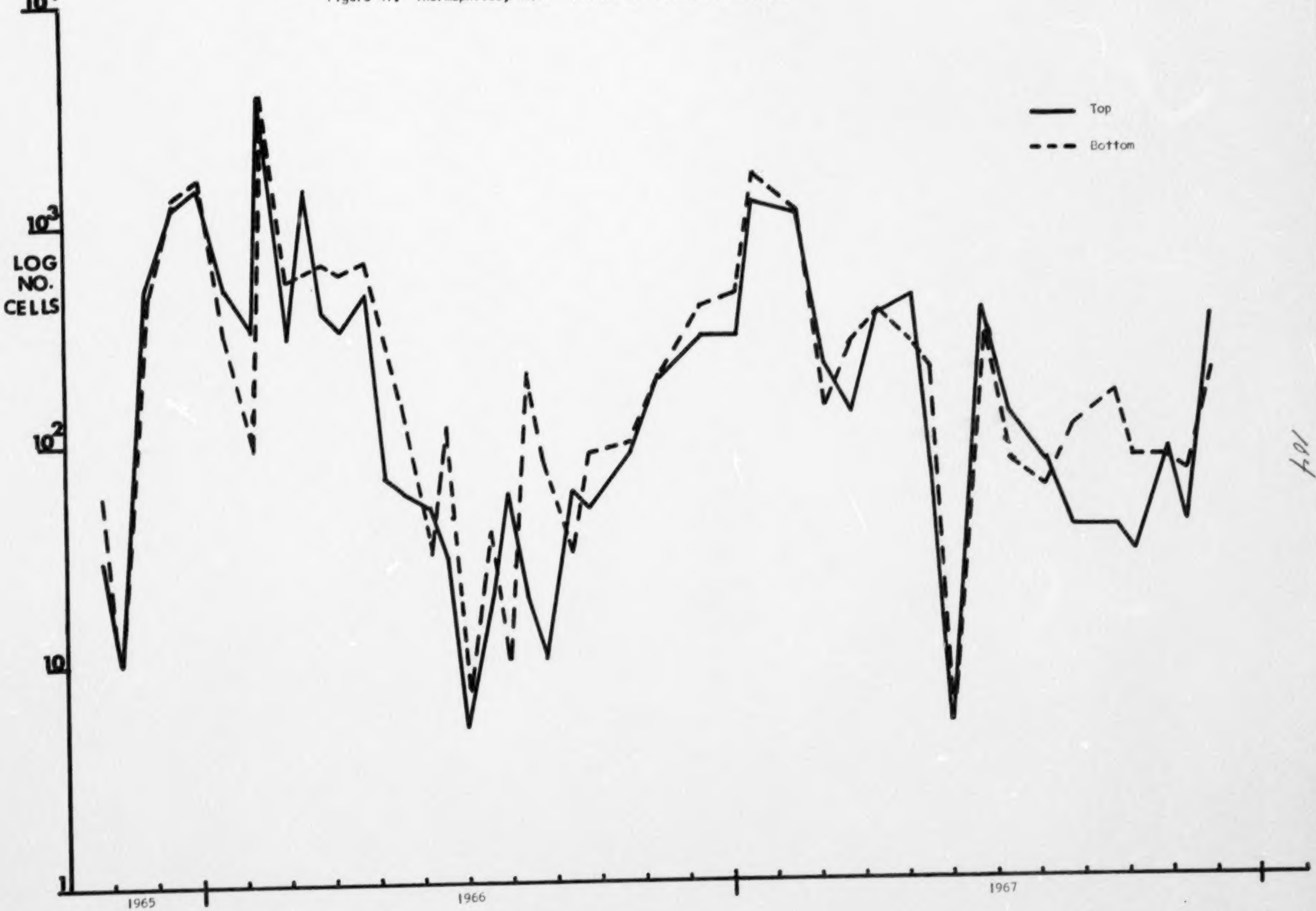
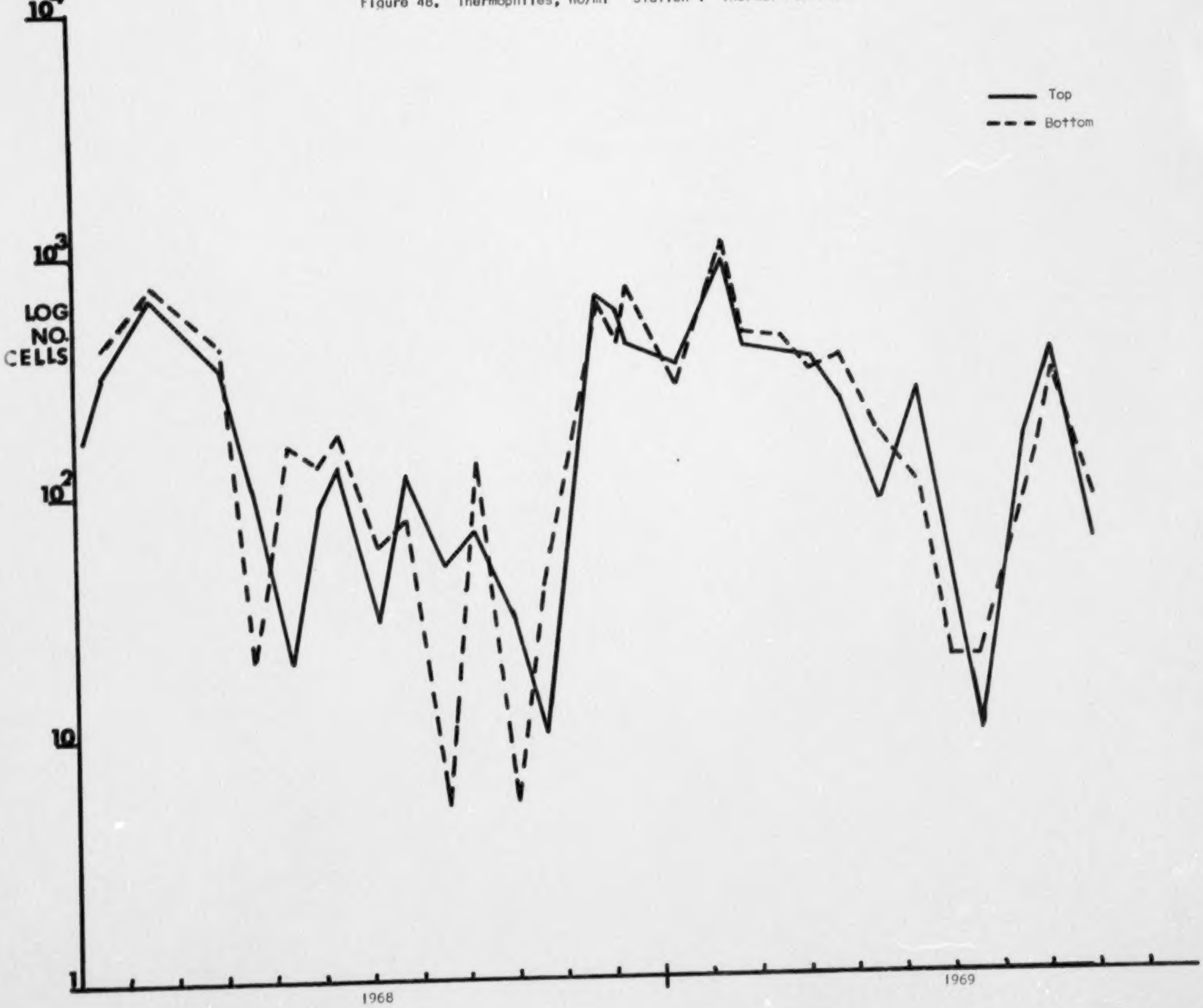


Figure 48. Thermophiles, no/ml Station I Thermal Period.



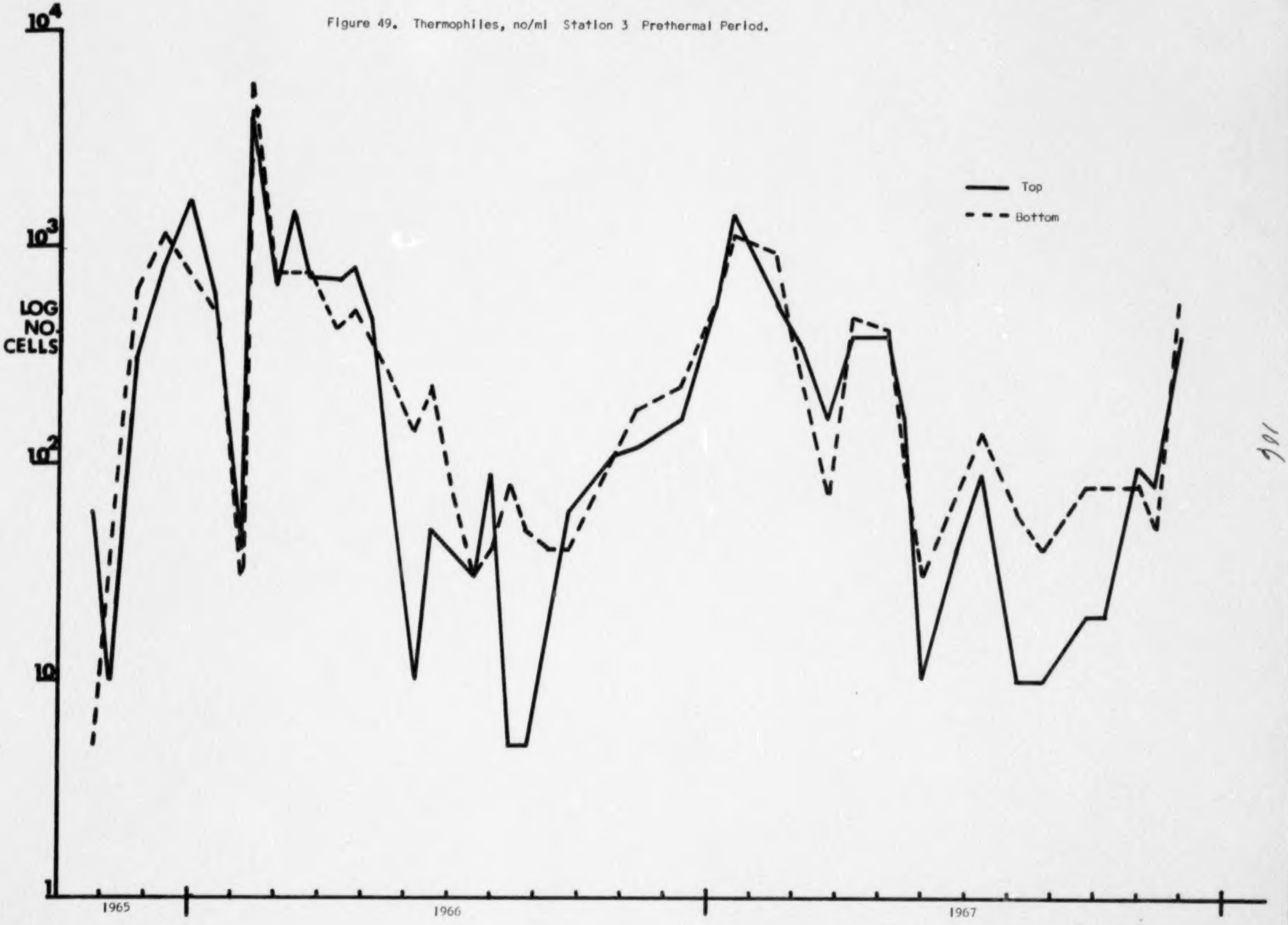


Figure 49. Thermophiles, no/ml Station 3 Prethermal Period.

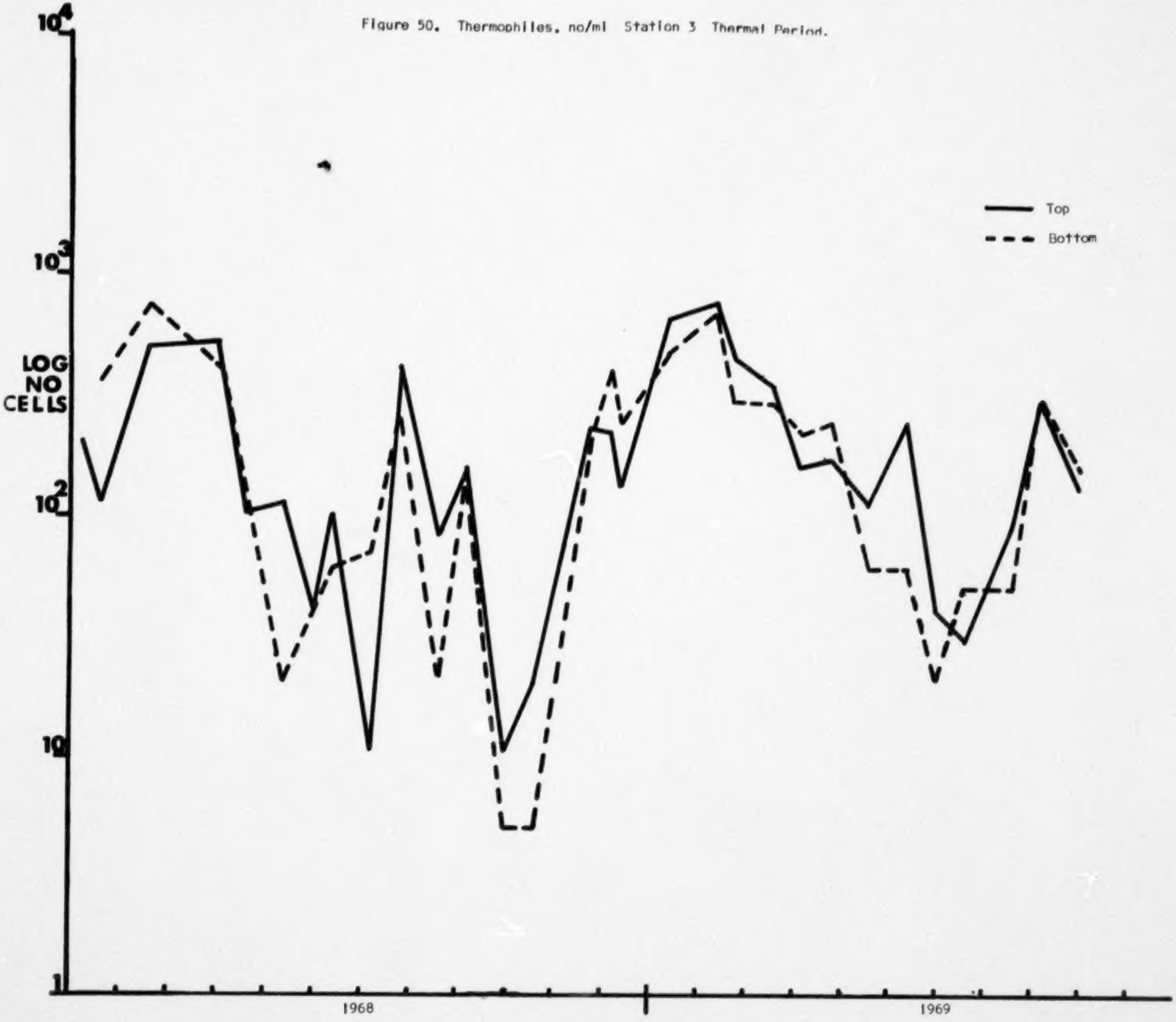
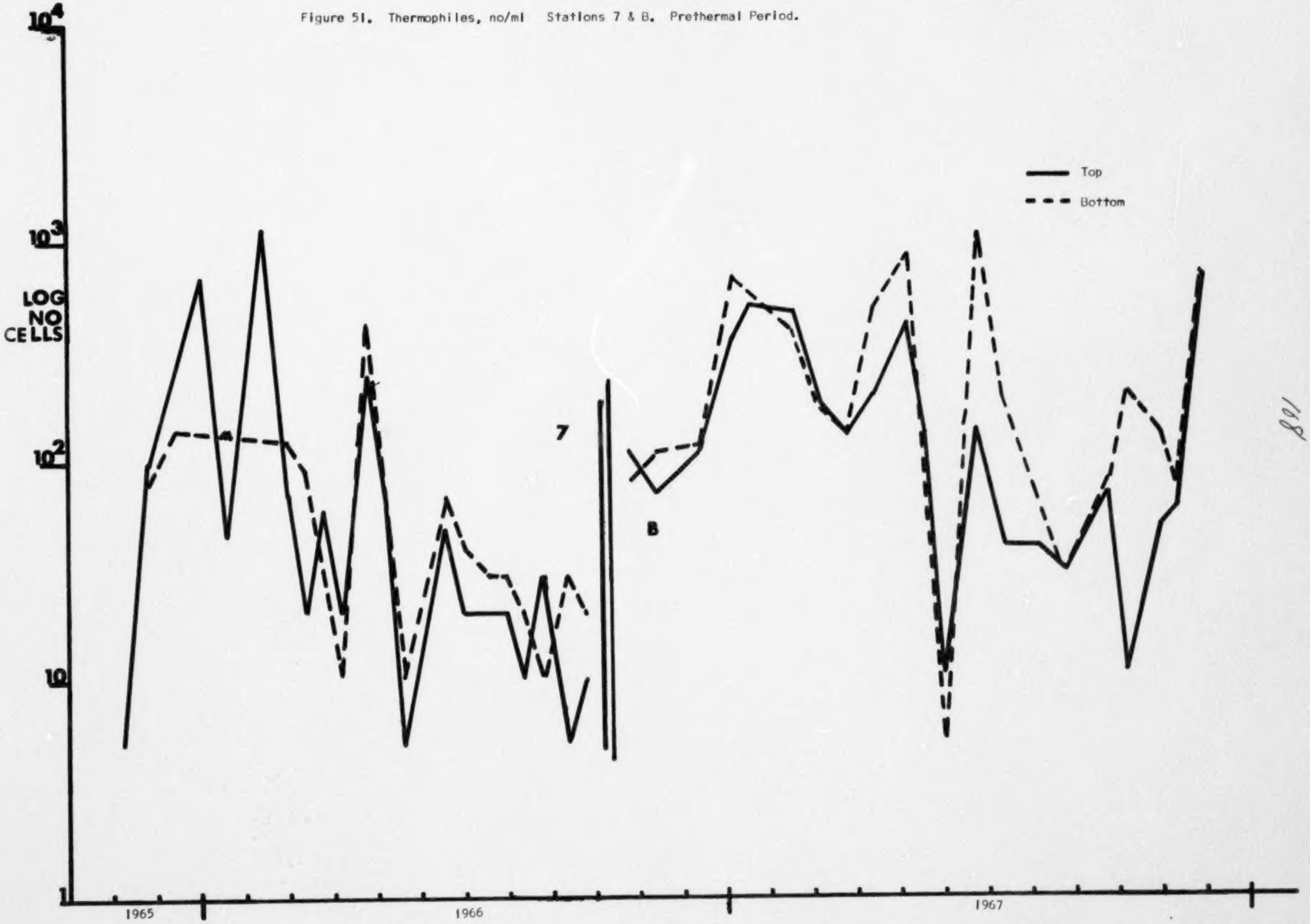


Figure 50. Thermophiles, no/ml Station 3 Thermal Period.

Figure 51. Thermophiles, no/ml Stations 7 & B. Prethermal Period.



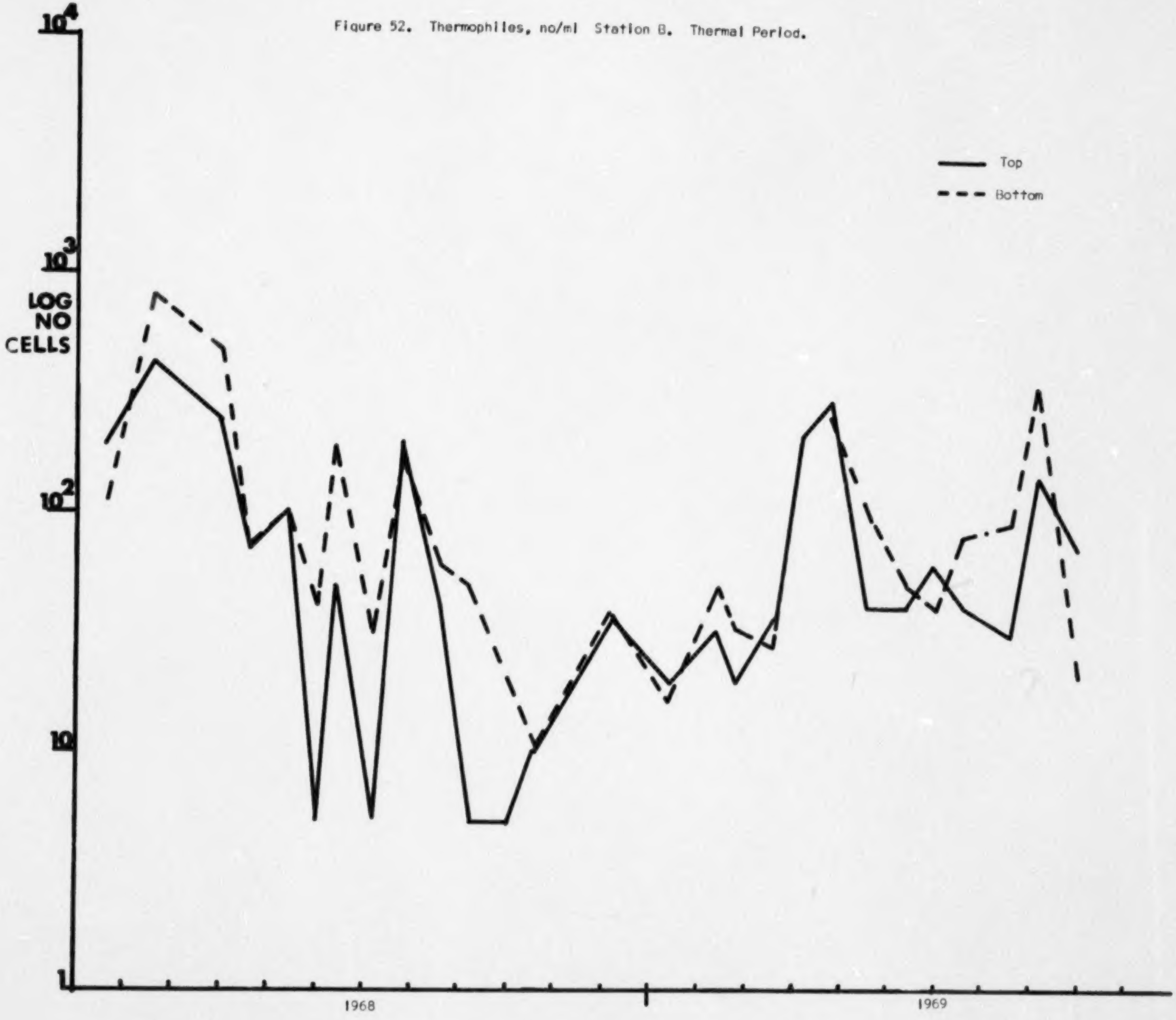


Figure 52. Thermophiles, no/ml Station B. Thermal Period.

No discrete differences were noted between stations or comparing prethermal and thermal periods.

The groups v and vi do not include very many bacteria which grow only at the low (5° C) or high (45-55° C) temperatures and there is considerable overlapping of growth temperatures in each grouping. As shown here, many organisms develop at the temperatures above but few are restricted to those temperatures alone. As a general rule, the optimal growth temperature of any organism is closer to its maximal survival temperature than the minimal survival temperature. The significance of thermal effluent lies therefore in creation of conditions above maximal for some organisms, particularly the psychrophiles. We did not, however, note any significant change in these forms after plant operation and conclude that River populations of obligate psychrophiles (and thermophiles) are very low. The ability to adapt to temperature as shown here by isolates is seen as a desirable physiological trait in a thermally enriched environment.

vii. Anaerobes. Counts of bacteria which can be cultured only in the complete absence of atmospheric oxygen varied randomly from a minimum of 250/ml to a maximum of 120,000/ml. There was little correlation between anaerobe counts and dissolved oxygen levels in the River; however, the maximum count recorded during the study coincided with a period of low dissolved oxygen (<4ppm) and high temperature (>80° F). Station 3 did not show any difference in anaerobe counts when compared to the other stations during either prethermal or thermal periods.

viii. Pollution-indicating bacteria. Total coliform counts (Figs. 53-58) were below the Class C maximum of 5000/100ml on only six sampling dates which occurred during various seasons and during each of the four years. Other than these samples, all counts indicate pollution levels corresponding to Class D waters (suitable for industrial and/or navigational purposes). Lowest counts correlated with flood tide stages. The major source of domestic

Figure 53. Coliforms, no/100 ml Station I. Prethermal Period.

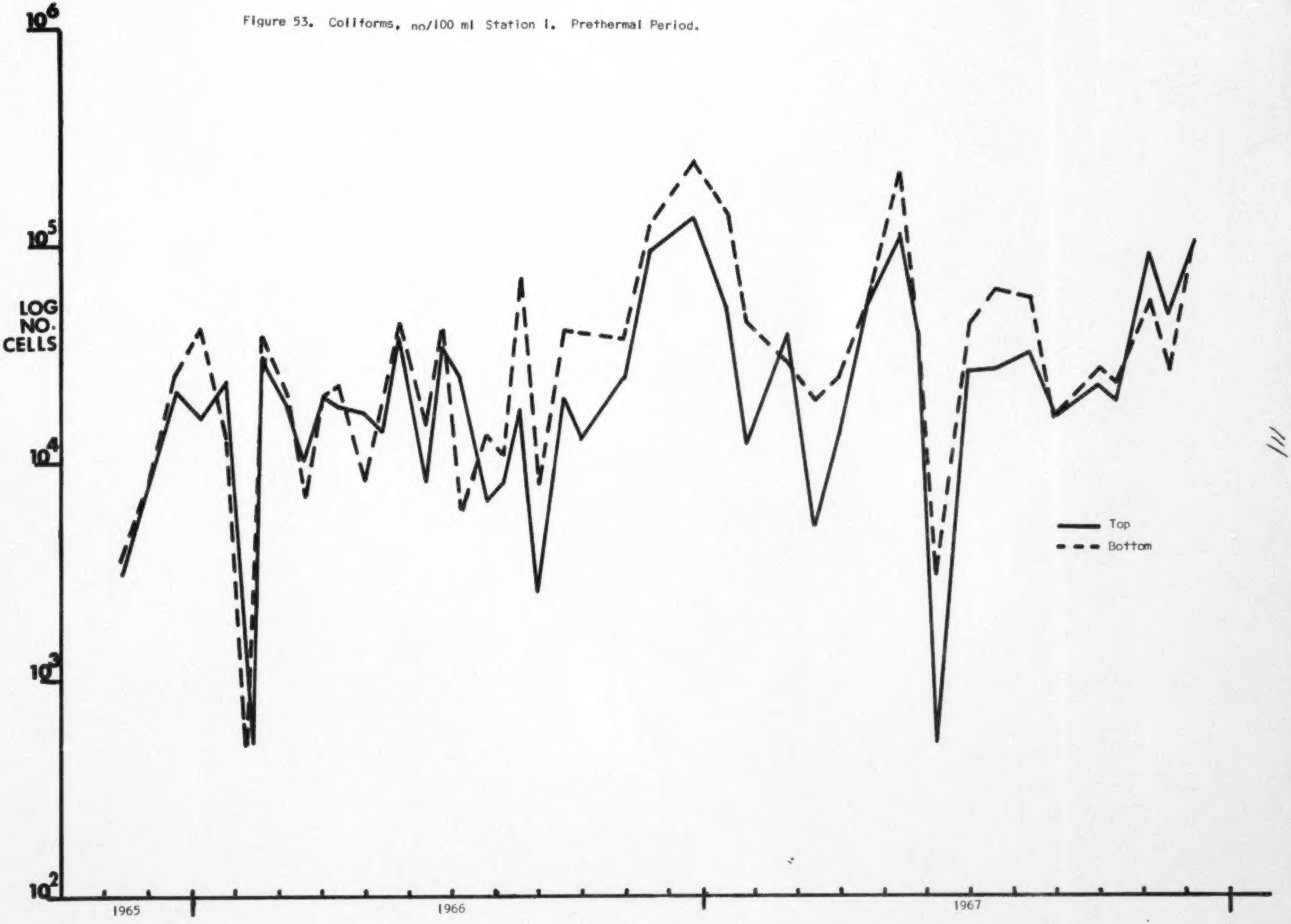
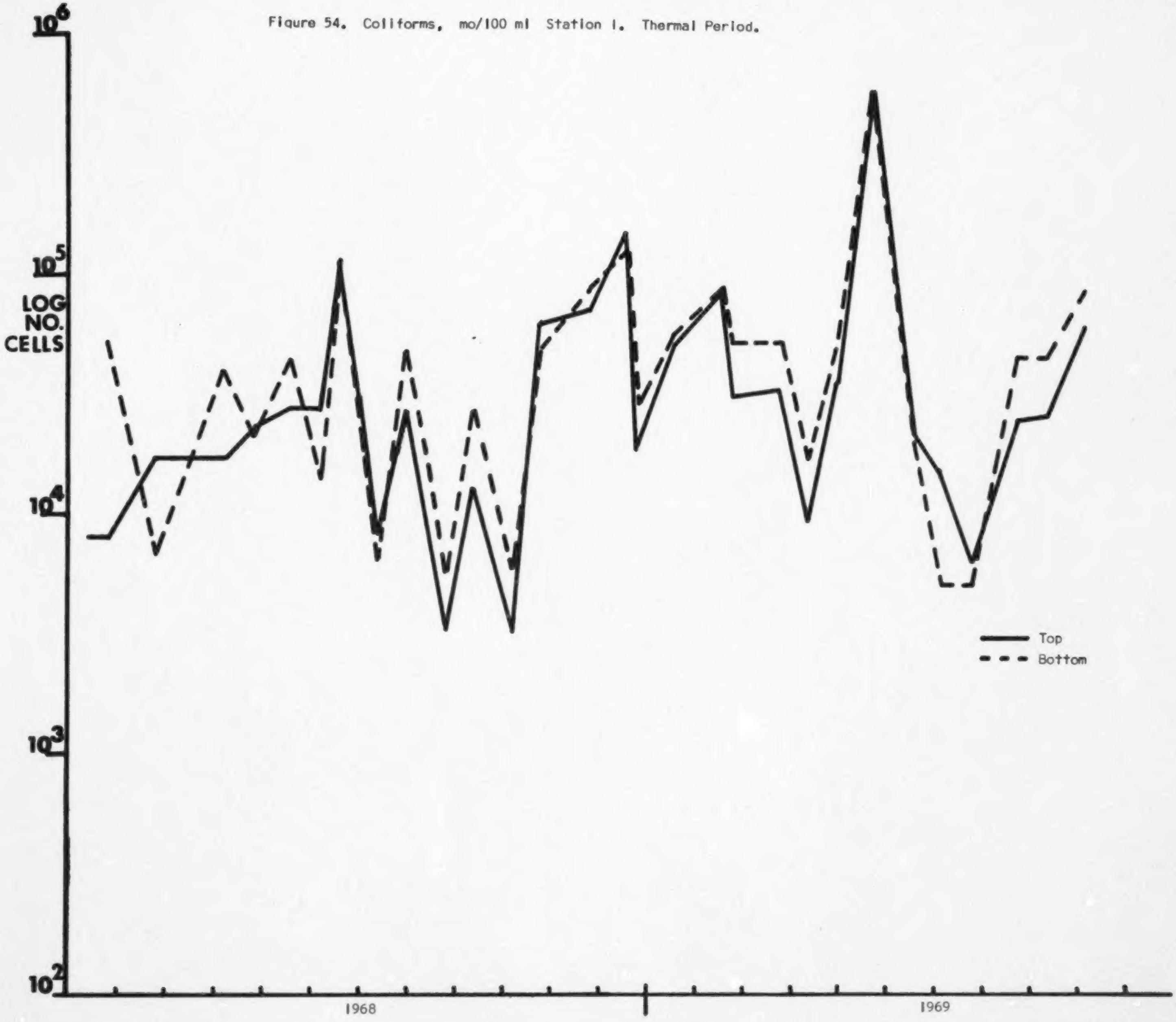


Figure 54. Coliforms, mo/100 ml Station I. Thermal Period.



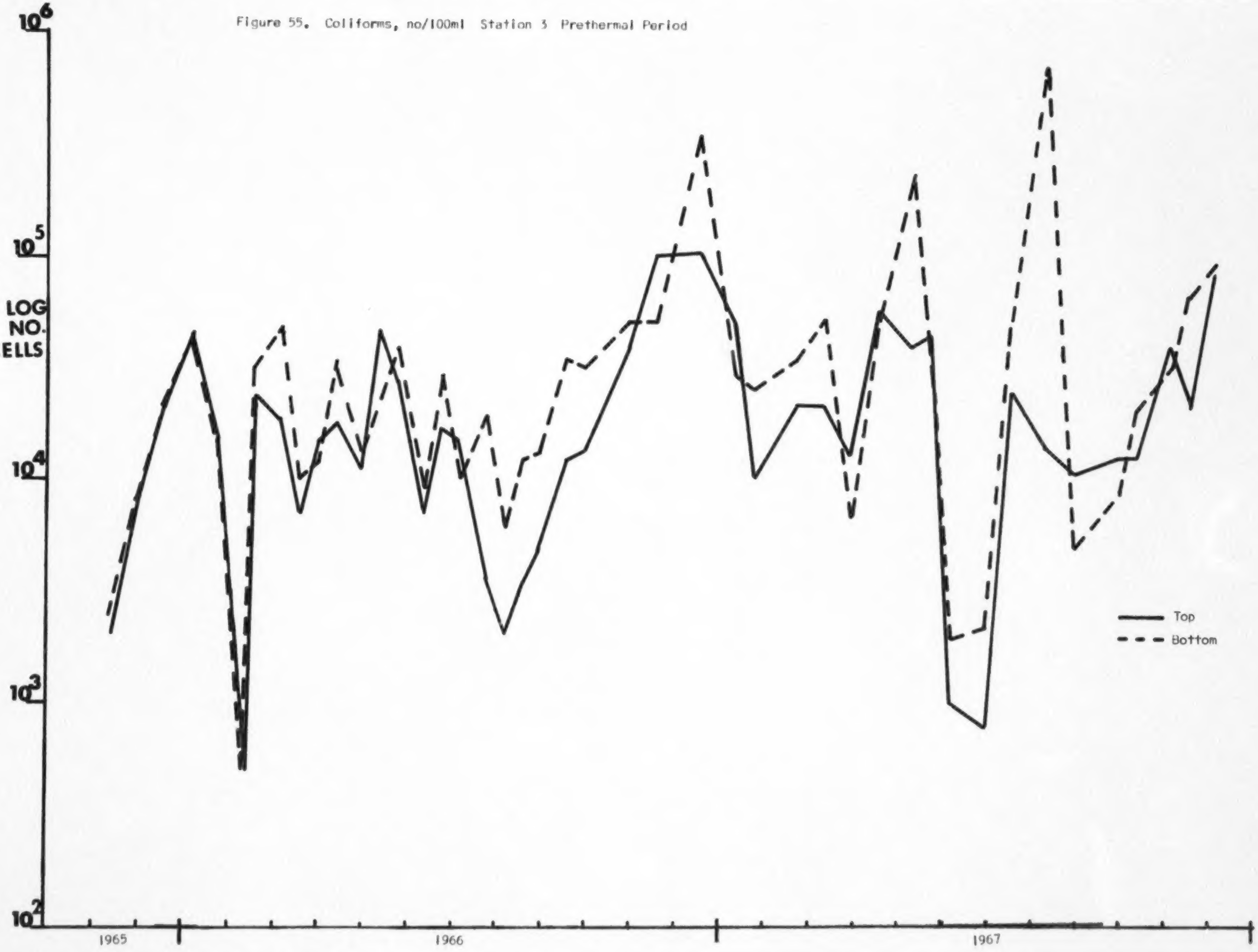


Figure 55. Coliforms, no/100ml Station 3 Prethermal Period

Figure 56. Coliforms. no/100 ml Station 3. Thermal Period.

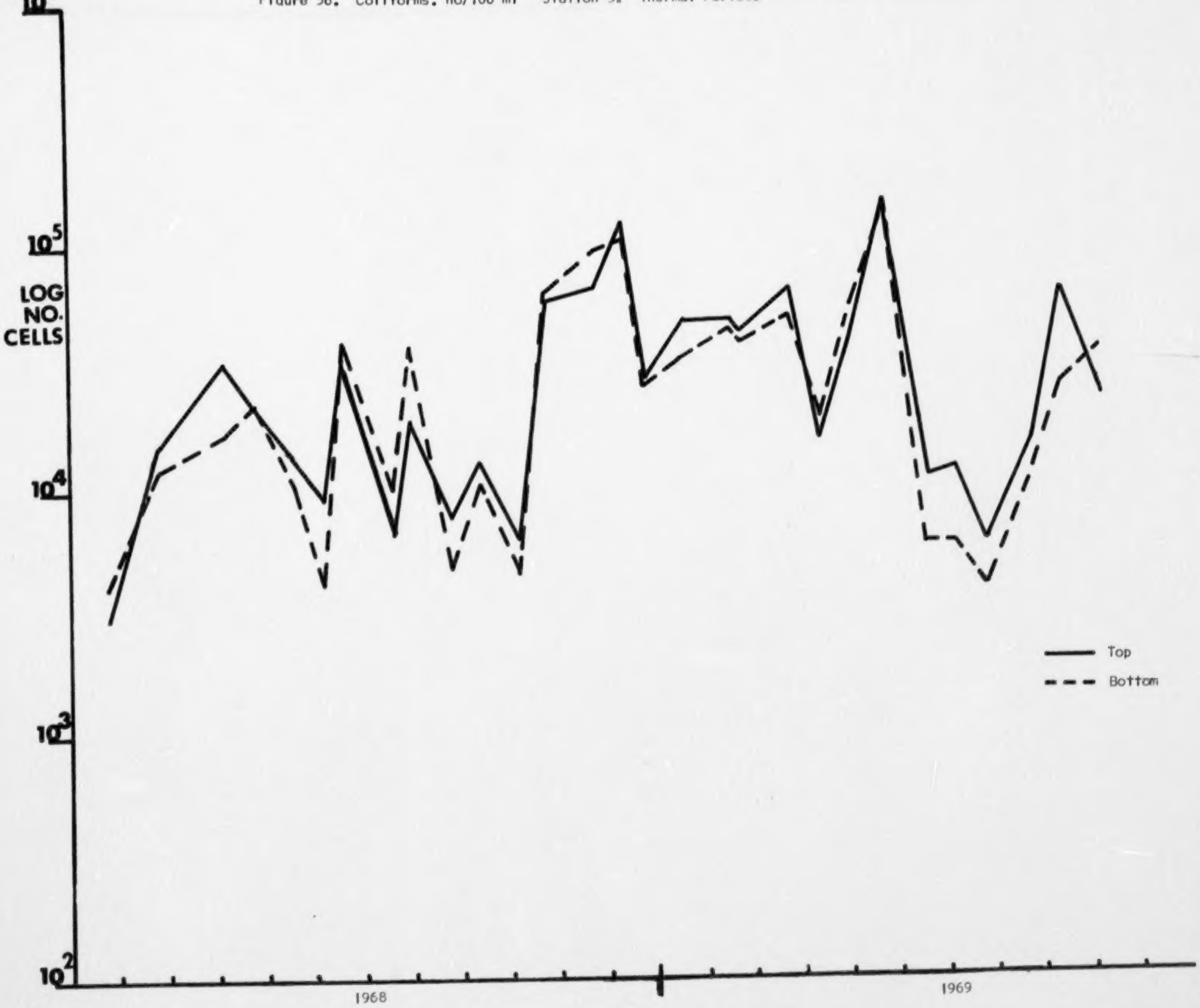


Figure 57. Coliforms, no/100 ml Stations 7 & B Prethermal Period

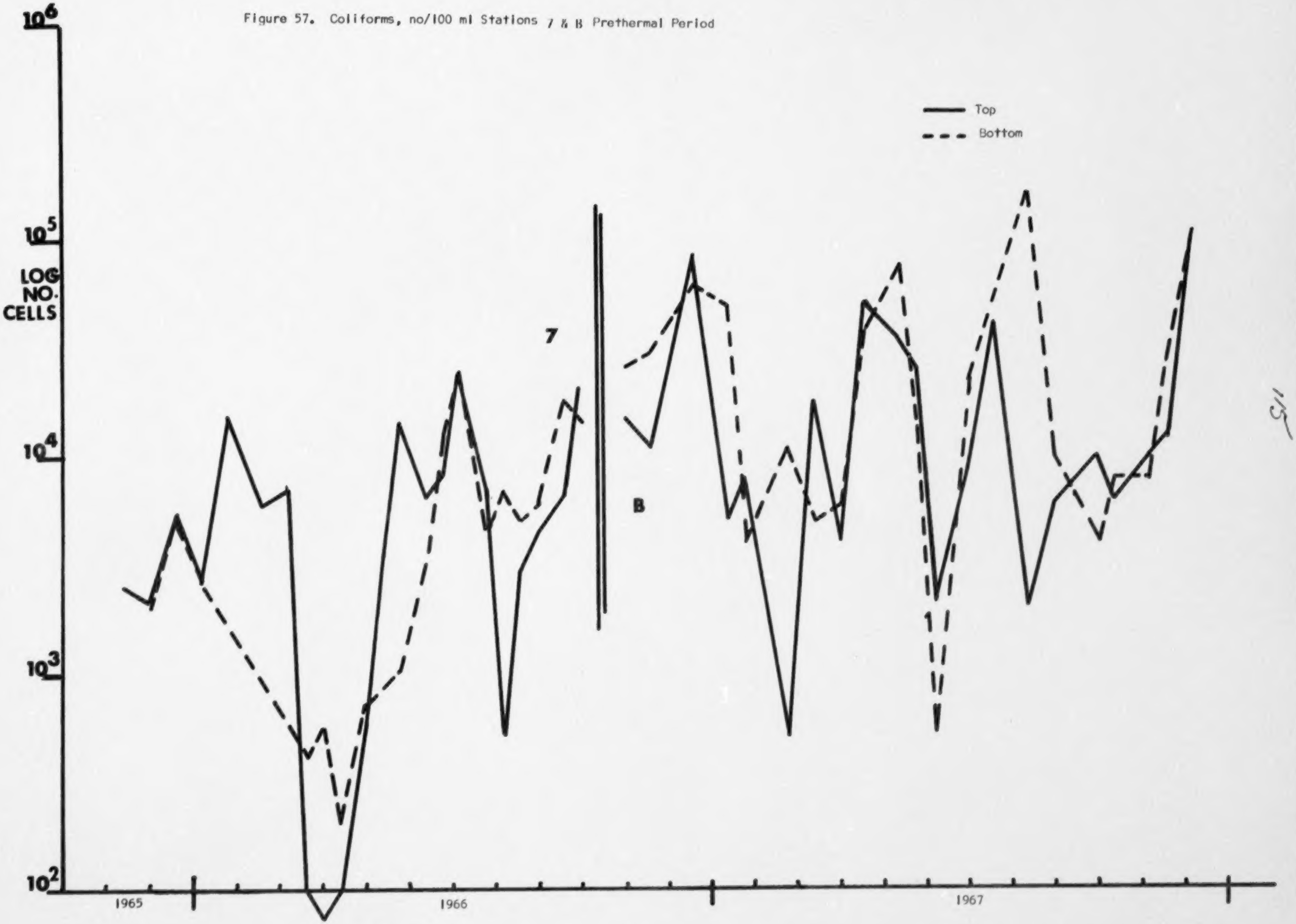
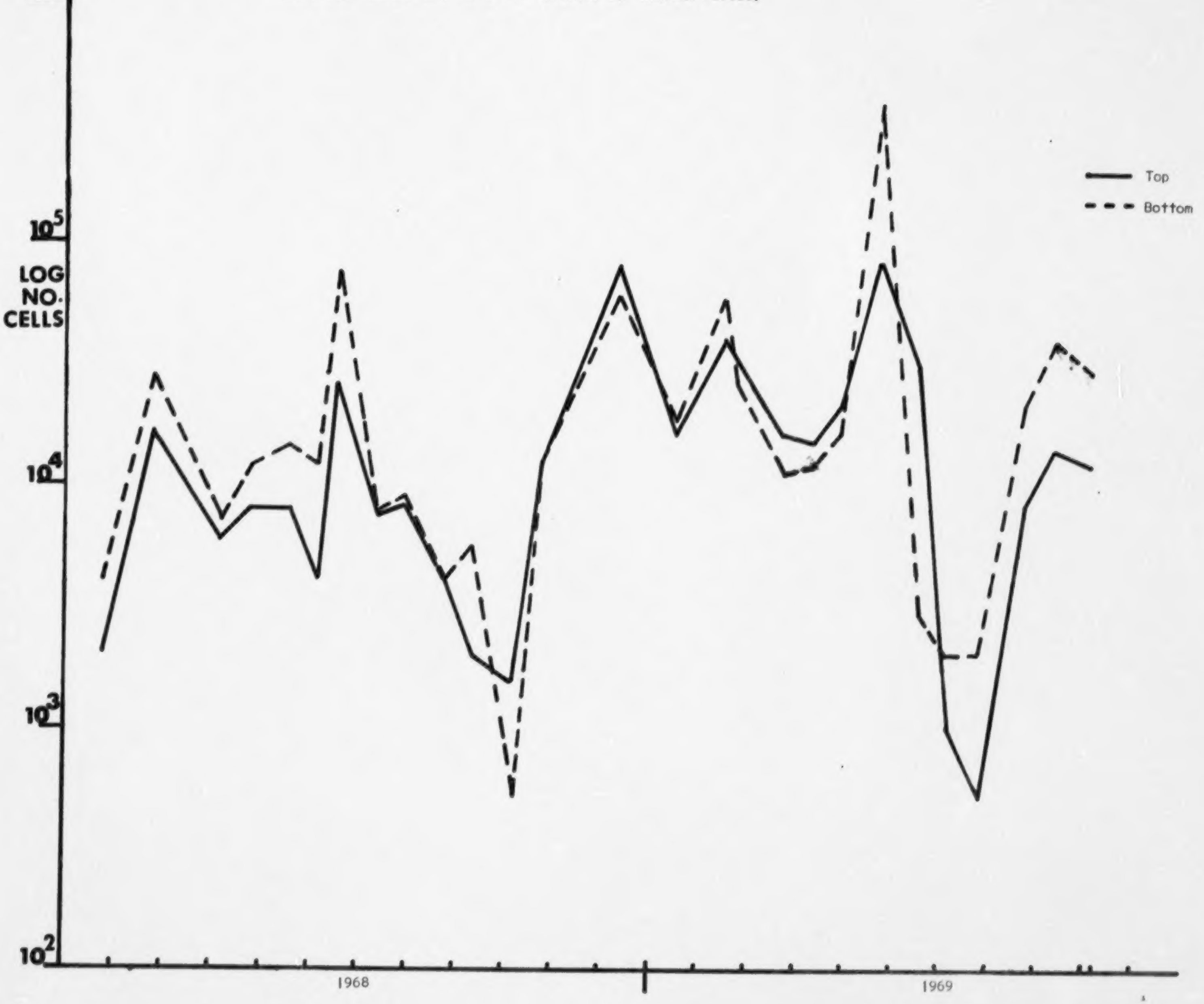


Figure 58. Coliforms, no/100 ml Station B. Thermal Period.



sewage in the area is the City of Middletown, Conn., upstream from the plant. Effluent from their primary treatment plant varies from 3-6 MGD depending on rainfall. The range of total coliform counts was from 700/100ml to 728,000/100ml. Counts varied randomly during all seasons, at all stations and during both prethermal and thermal periods.

Counts of fecal coliforms (Figs. 59-64) varied from a low of 86/100 ml to >13,000/100ml. There was some indication of a cyclical trend toward lowest counts during the summer and early fall. Sewage effluent from Middletown is chlorinated only during the period May through September and may account for these observations. Otherwise, no station or thermal influences were noted.

Fecal streptococci (enterococci) varied from 3->4,000/100 ml (Fig. 65-70). A pronounced decrease in numbers at all stations was recorded in the summer and early fall.

ix. During the early portion of the study, water samples were examined for cellulolytic, chitinolytic and anaerobic sulfate-reducing bacteria. Use of cellulose medium was discontinued in May of 1966 since no cellulolytic bacteria had been isolated up to that time. Since chitin-hydrolyzers were detected in very low numbers during the first two years, their enumeration was discontinued in April of 1968. Counts of sulfate-reducing bacteria were terminated in October of 1966; the method employed was time-consuming and gave at best only an estimate of populations.

Counts of yeasts and molds were discontinued at the end of the first year at the suggestion of our technical advisors on the basis of time expended and the dubious value of these organisms in assessment of water quality. Considerable effort, however, (e.g. 81) has been concentrated on the role of yeasts and molds in the sewage treatment process and may yet indicate their significance in polluted aquatic habitats.

Figure 59. Fecal Coliforms, no/100 ml; Station I Prethermal Period

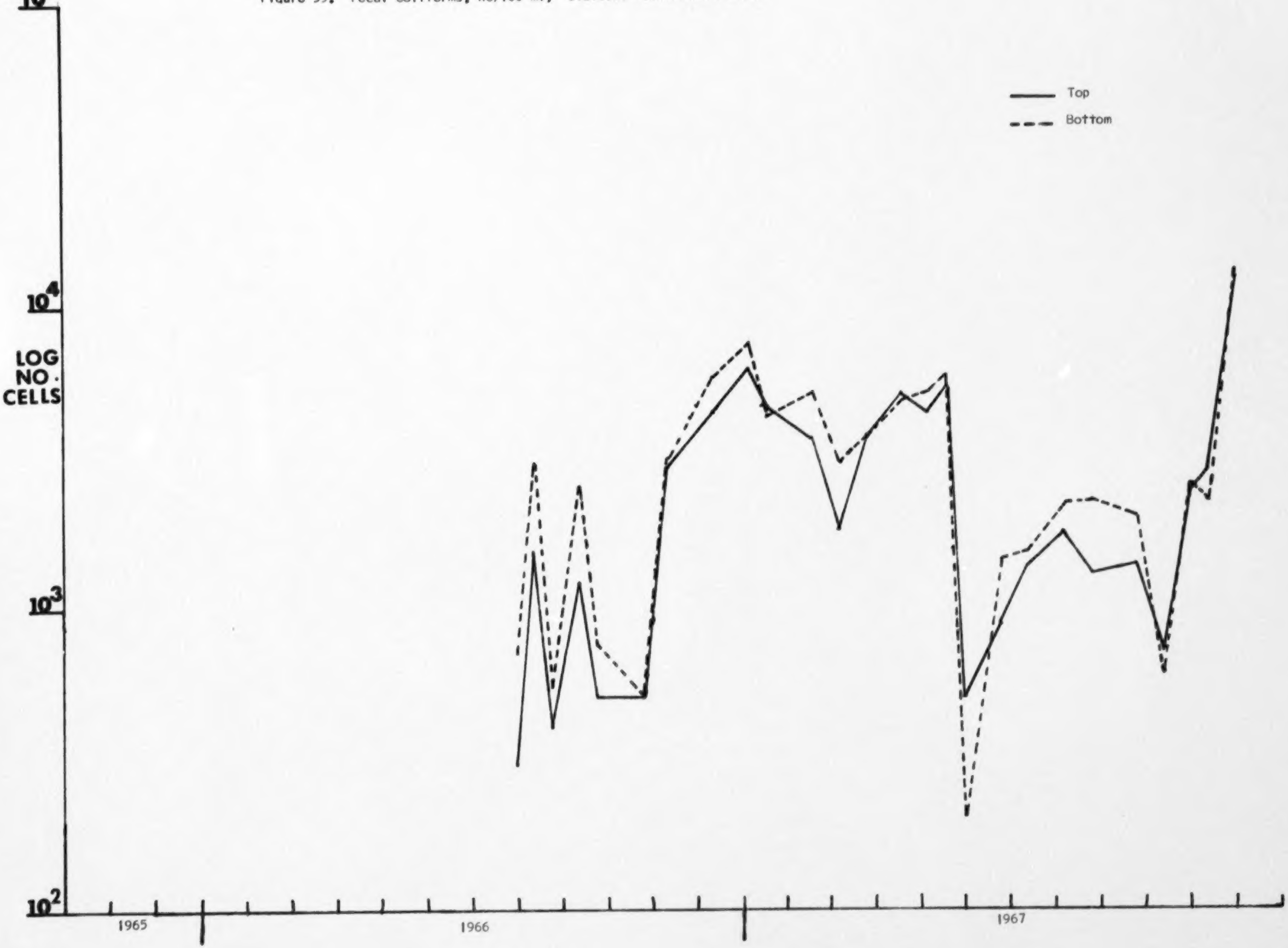


Figure 60. Fecal Coliforms, no/100ml. Station I. Thermal Period.

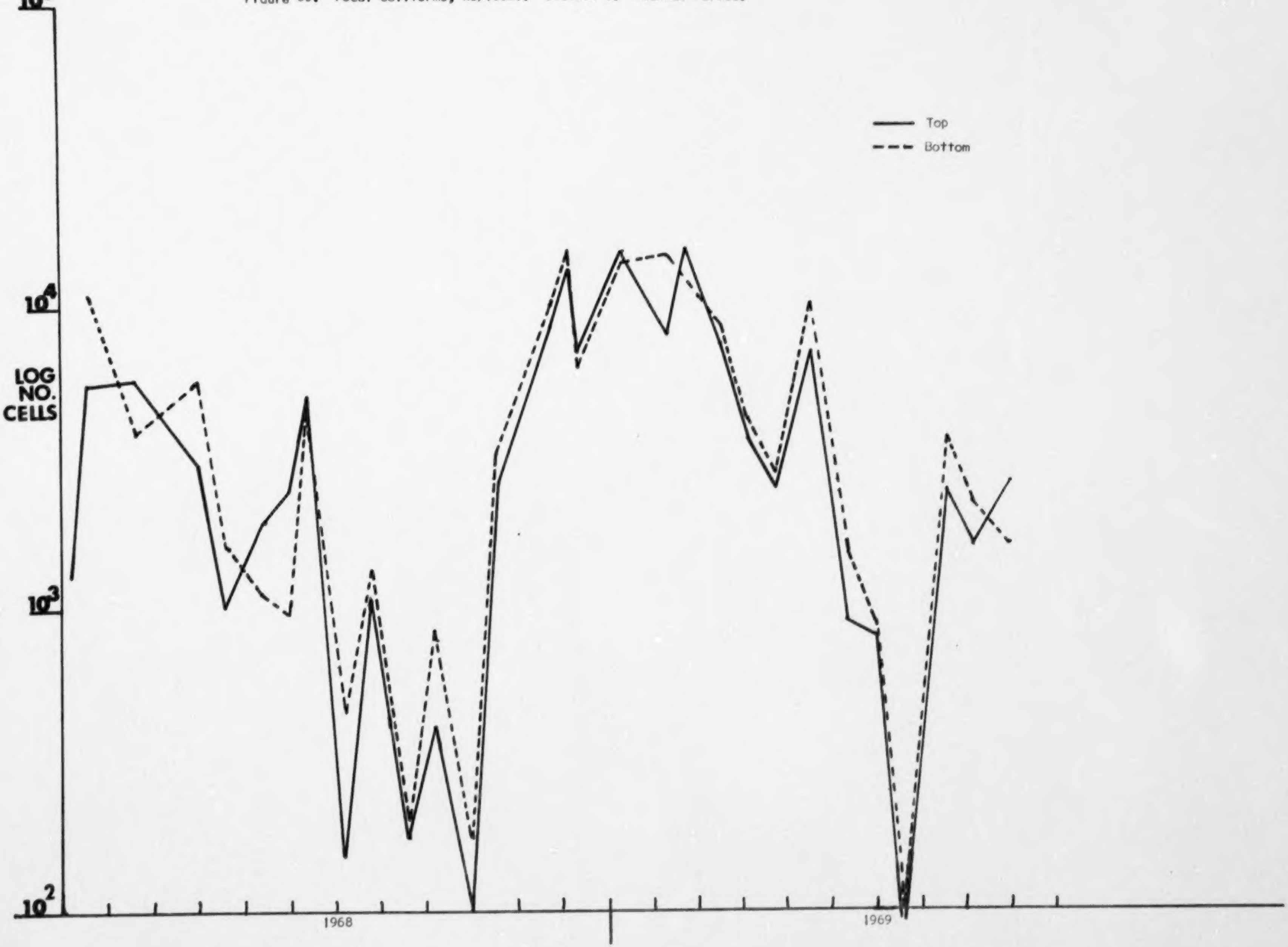


Figure 61. Fecal Coliforms, no/100 ml. Station 3 Prethermal Period

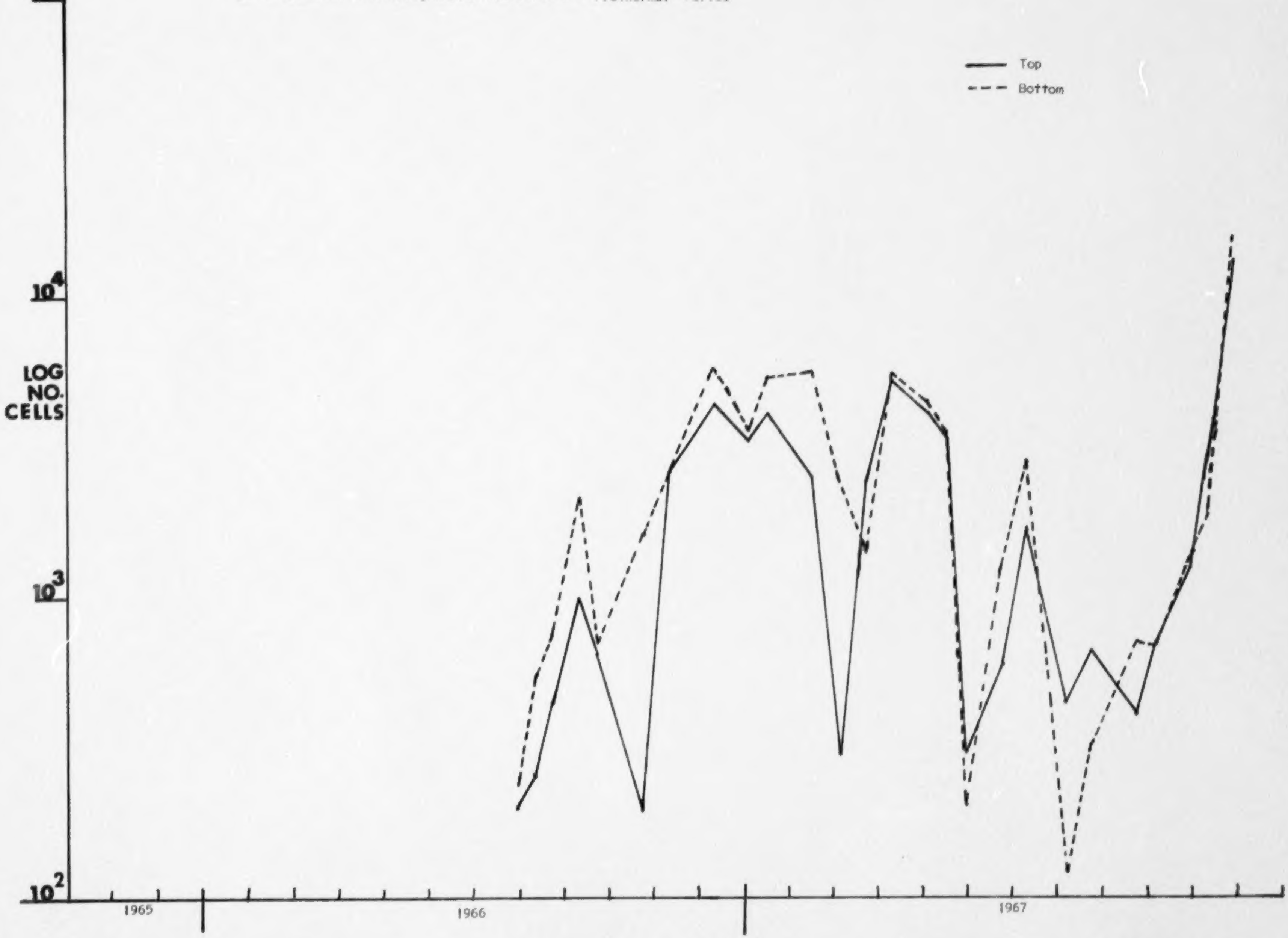


Figure 62. Fecal Coliforms. no/100 ml; Station 3. Thermal Period.

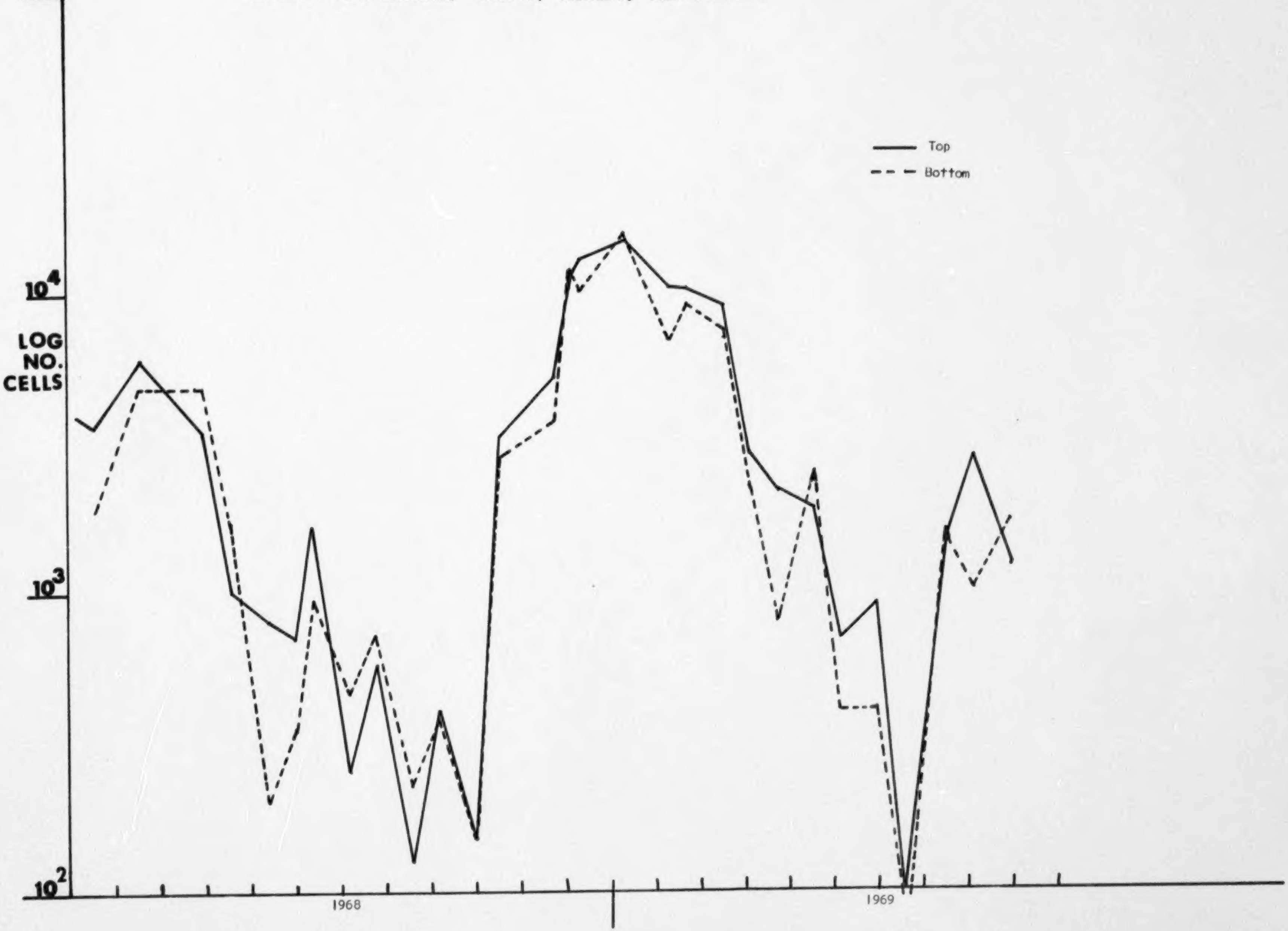


Figure 63. Fecal Coliforms, no/loo ml; Stations 7 & B Prethermal Period.

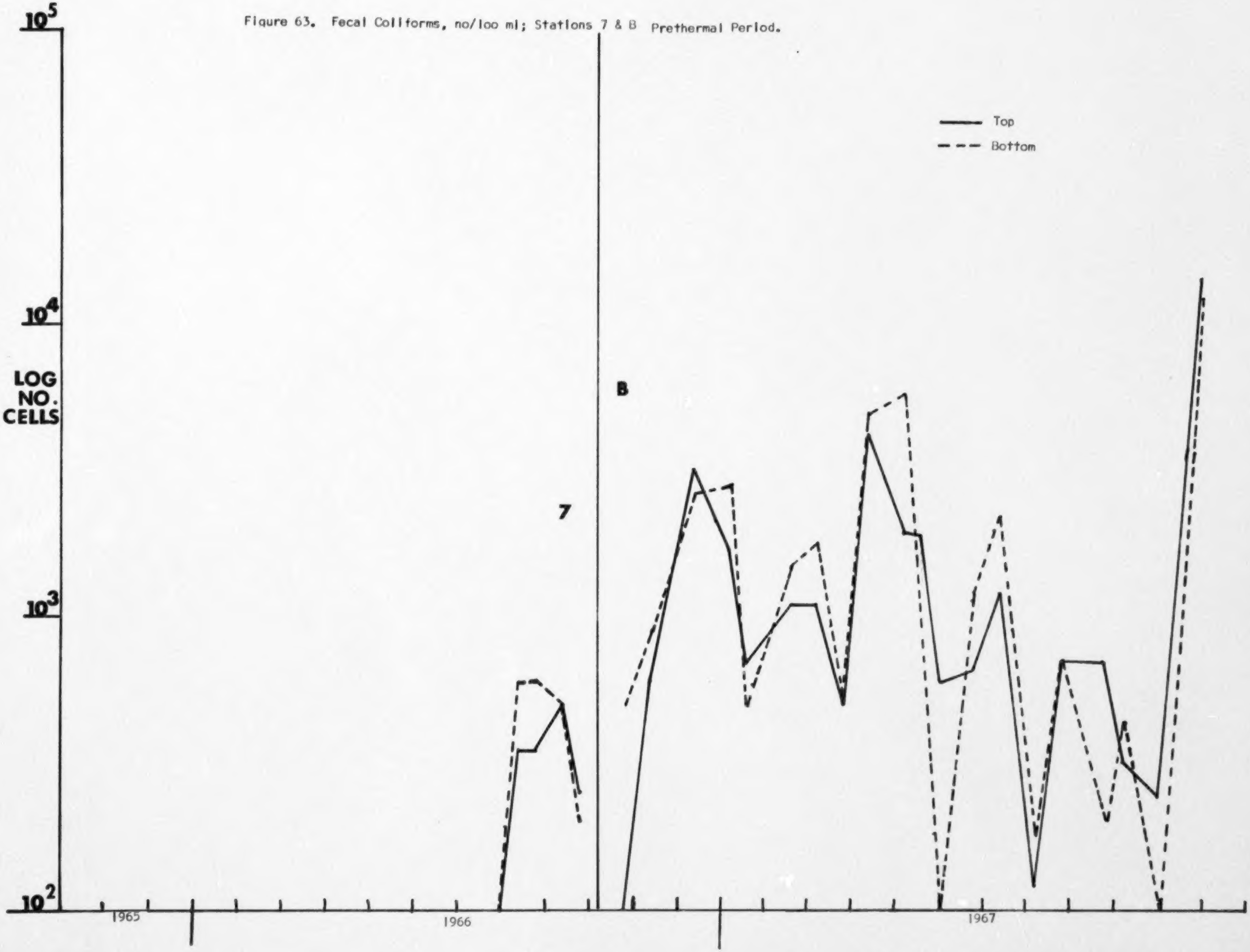


Figure 64. Fecal Coliforms no/100 ml Station B. Thermal Period

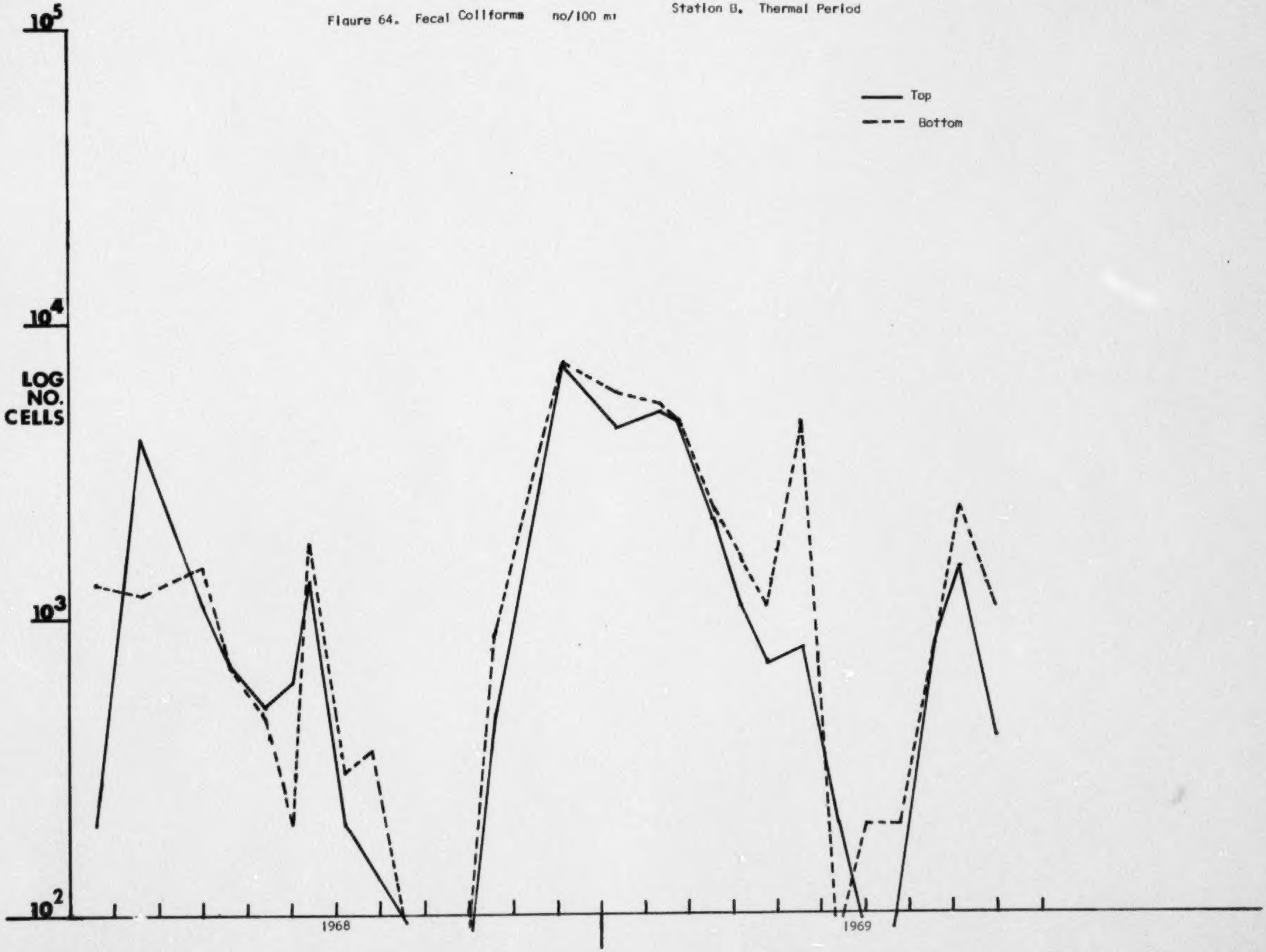


Figure 65. Enterococci, no/100ml; Station I. Prethermal Period.

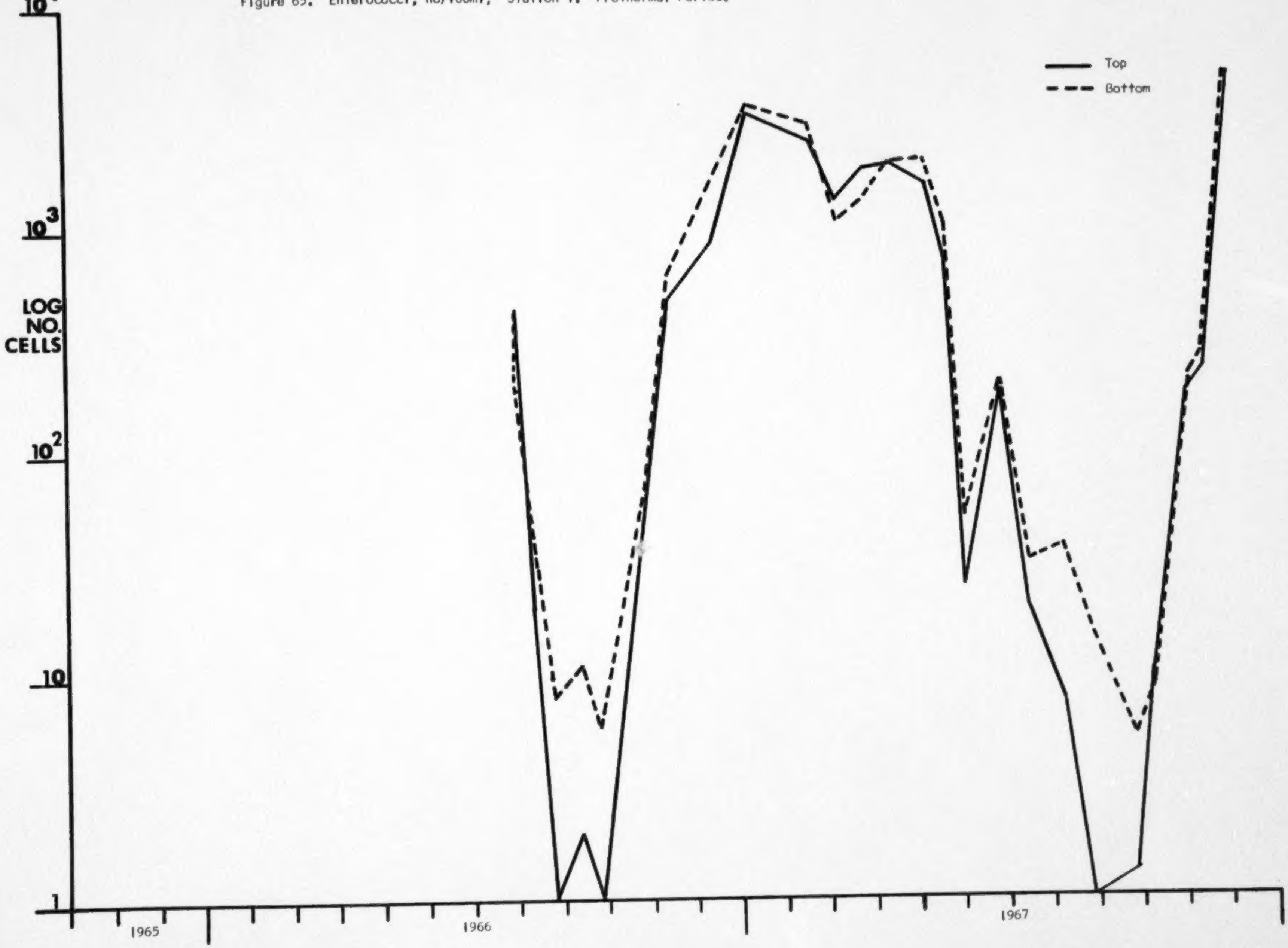


Figure 66. Enterococci, no/100 ml. Station I Thermal Period

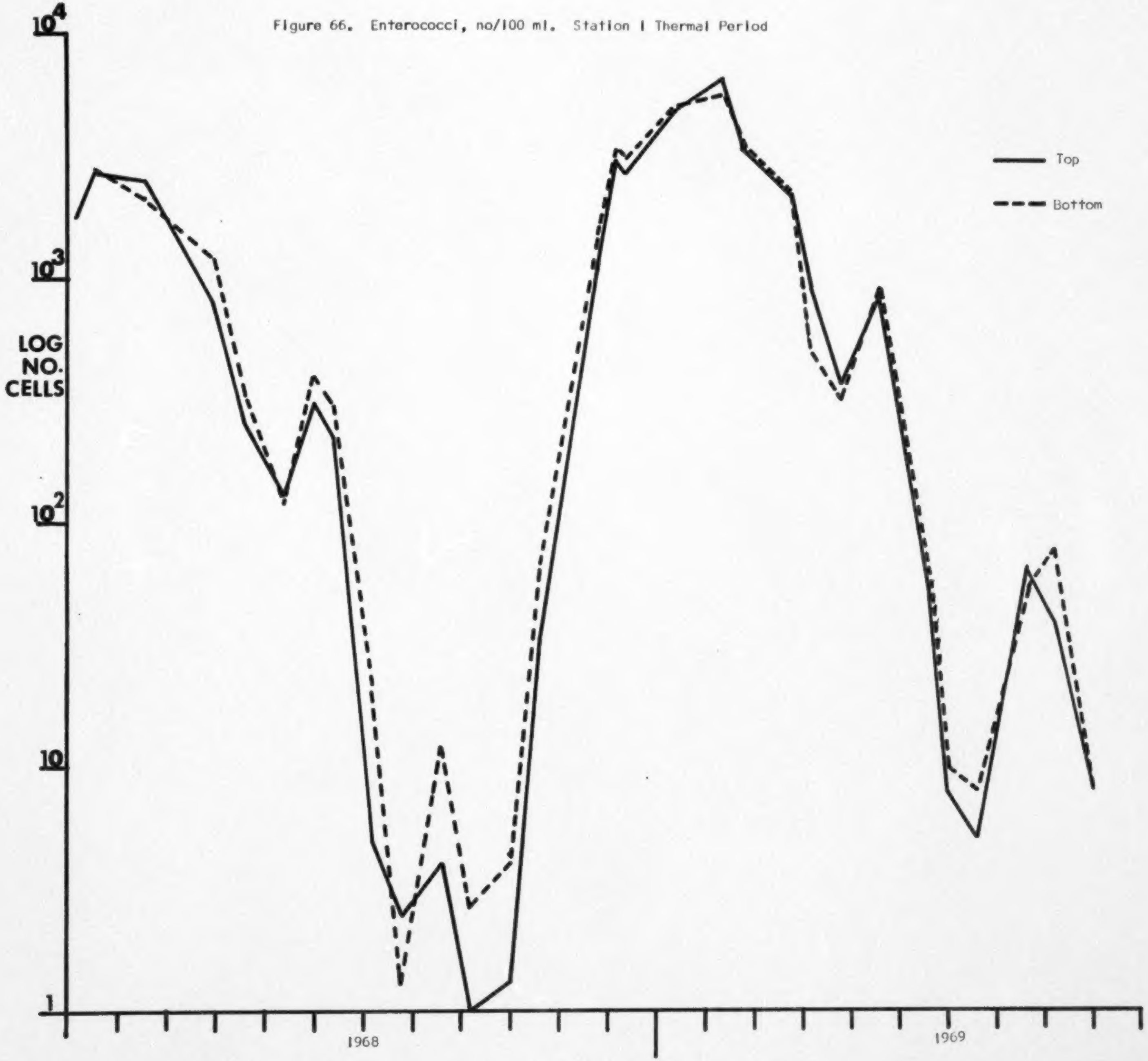


Figure 67. Enterococci, no/100ml. Station 3. Prethermal Period.

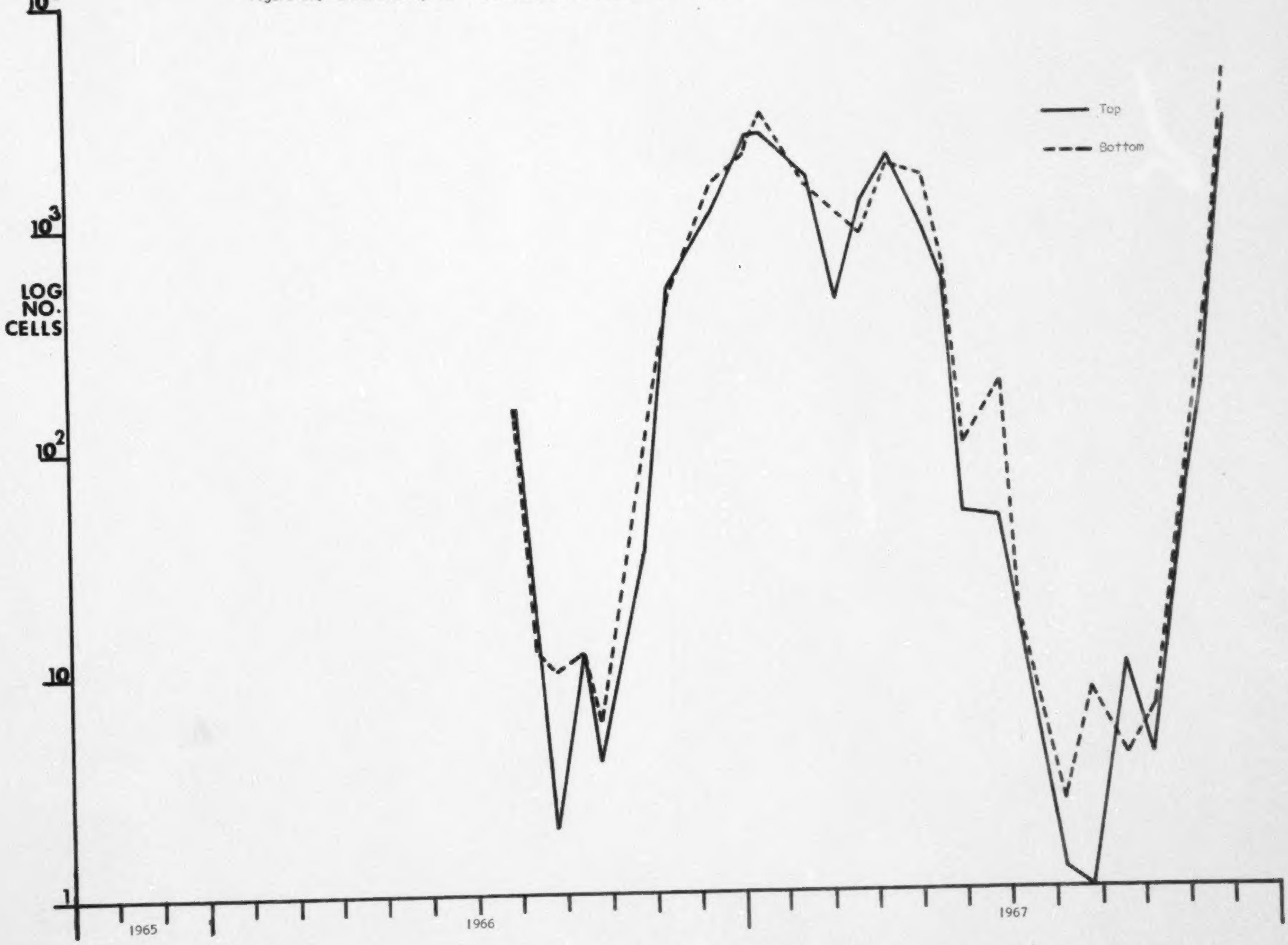


Figure 68. Enterococci, no/100 ml; Station 3 Thermal Period.

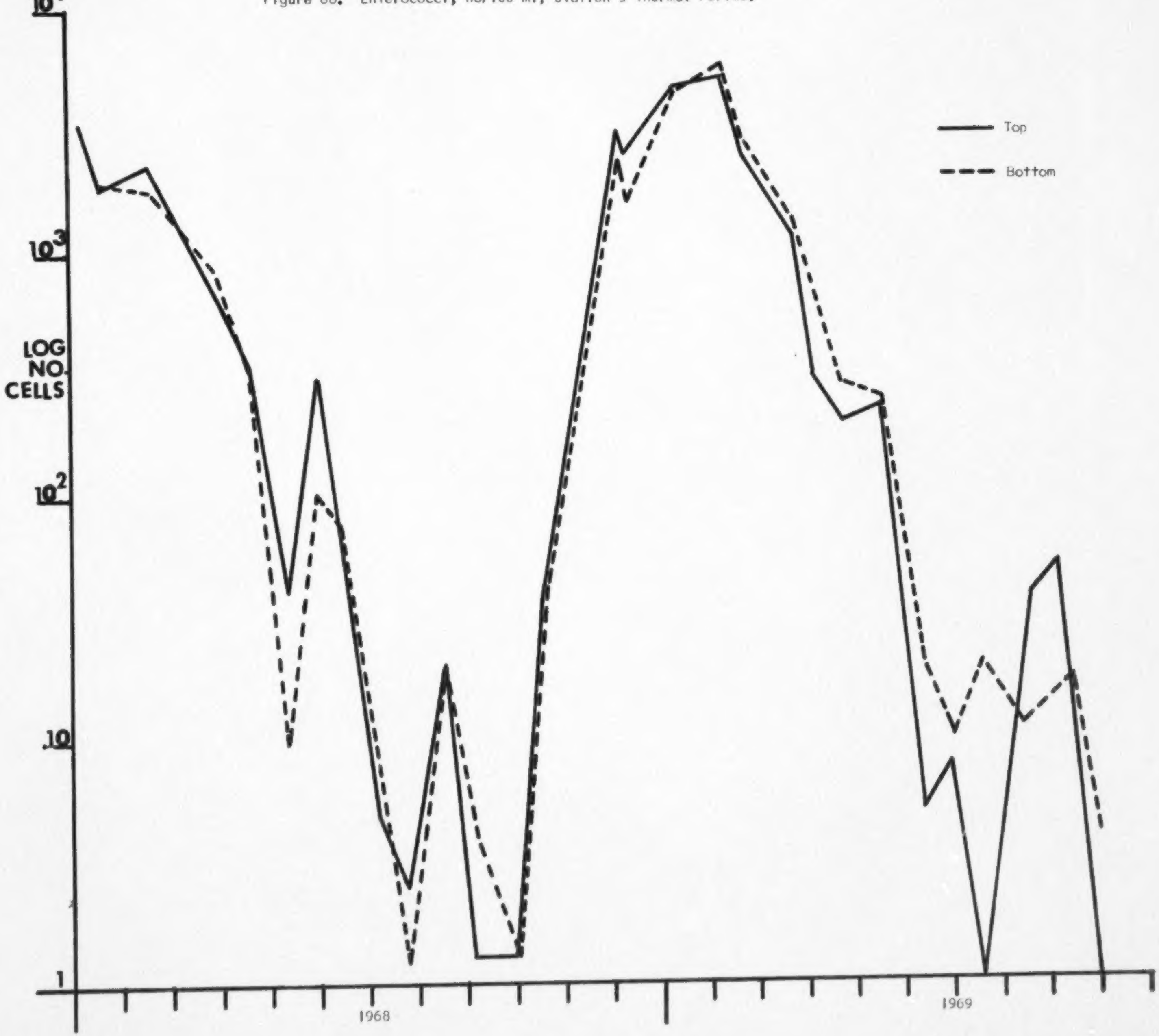


Figure 69. Enterococci, no/100 ml. Stations 7&B Prethermal Period.

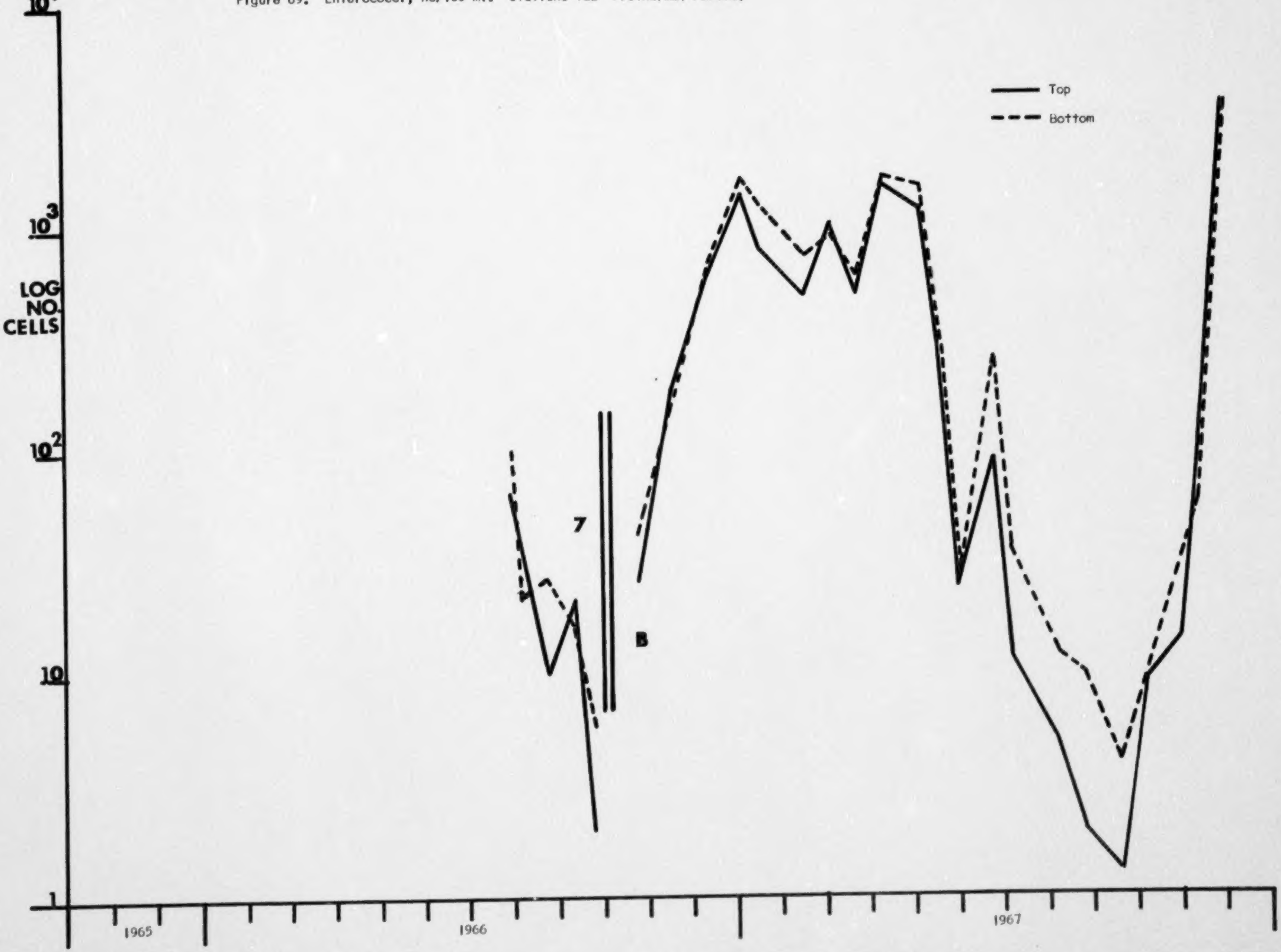
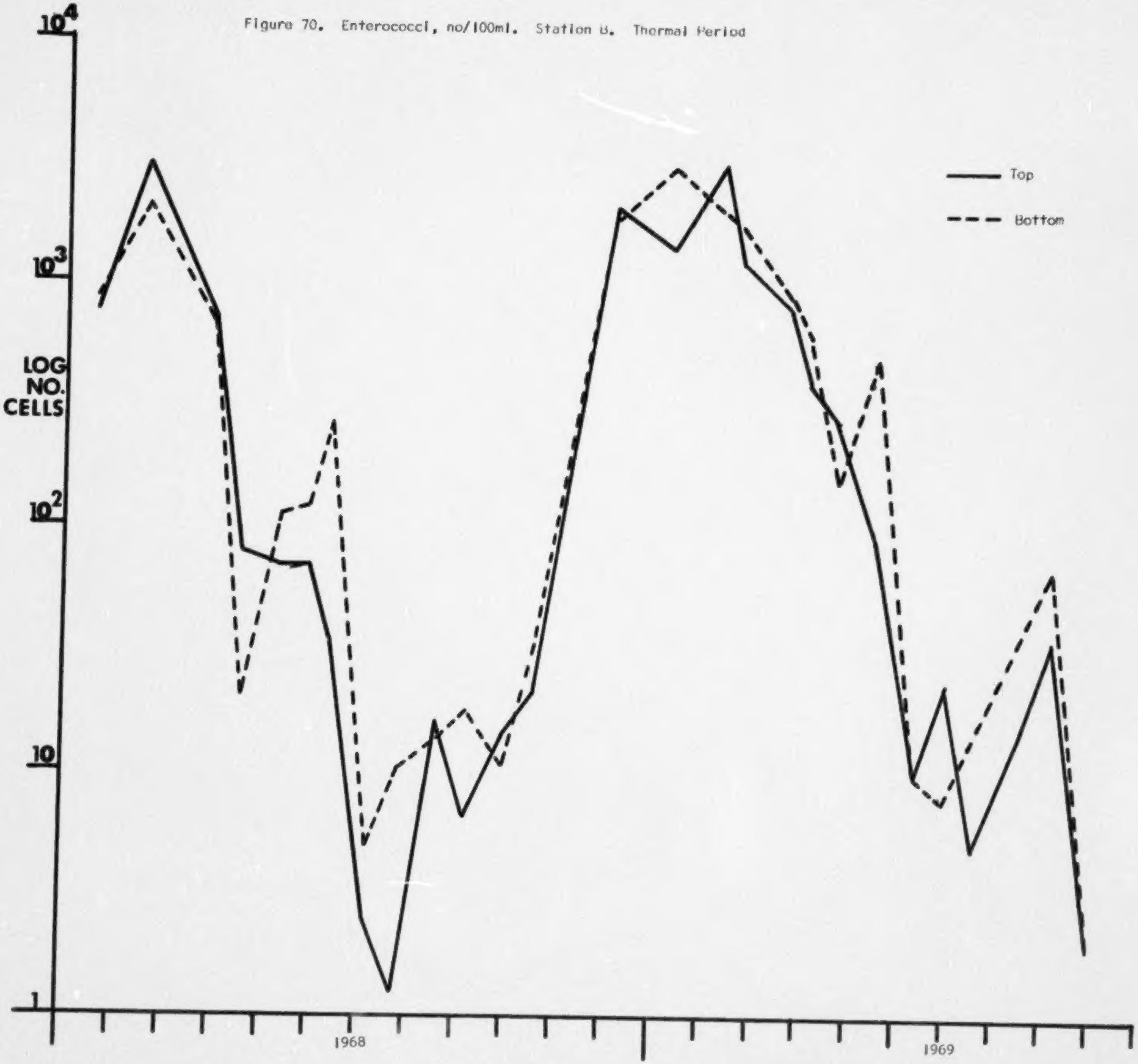


Figure 70. Enterococci, no/100ml. Station B. Thermal Period



B. Laboratory Studies - Bacteria

1. Generic identification of total count isolates. Table 9 (82,83) is included as an aid to the evaluation of the observations below. Table 10 shows the overall numbers and percentages of the various groups isolated from "total count" plates at all stations during both prethermal and thermal periods; total numbers of isolates from both periods were similar. A general decline in the *Achromobacter-Alcaligenes* and coryneform groups was noted, along with an increase in Enterobacteriaceae, *Pseudomonas* and the *Flavobacterium-Cytophaga* group. However, none of these numbers represented gross quantitative or qualitative changes in the microflora. Nor are any drastic changes seen when plotted as a function of season (Fig. 71), although there were some indications that the pseudomonads were more prevalent during Fall months. Essentially, only the *Pseudomonas* and *Achromobacter-Alcaligenes* groups were consistently isolated throughout the entire study period. In comparing our data with a previous study (84) during 1964-1965 in the same area of the Connecticut River we find that, while the same genera or groups of bacteria were dominant and the frequencies were similar, the actual percentage of the various organisms found were inconsistent; i.e., no trends upward or downward in occurrence were apparent from the 1964 study through the termination of our work in 1969.

If we now take these overall data for all stations and consider them individually by station (Figs. 72-81), both the randomness and clustering of isolation of the various groups can be seen. Top and bottom data for Station 3 were treated separately since our sampling site was often in a stratified region of the River. Again, considering the relatively small number of isolates, little significance can be attached to these plots.

TABLE 9. Habitat and Biochemical Activities of the Most Commonly-Isolated Bacteria from the Connecticut River.

Genus or Group	Natural Habit	Relevent Biochemical (or other) Properties
Achromobacter-*Alcaligenes*	Salt or fresh waters, soil, intestinal tract of invertebrates	Some species proteolytic and lipolytic; some carbohydrates utilized by a few species:
Bacillus	Soil	Actively proteolytic and saccharolytic; produce resistant endospores.
Corynebacterium	Plants, soil	Some species proteolytic and saccharolytic.
Enterobacteriaceae	Intestinal tract of man and other animals, plants, soil (Generally associated with sewage)	All species saccharolytic.
Flavobacterium-*Cytophaga*	Soil, fresh and marine waters	Many species proteolytic and/or saccharolytic; some species cellulolytic; nonlipolytic.
Pseudomonas	Soil, fresh and marine waters	Many species proteolytic, saccharolytic and/or lipolytic. May utilize very simple salts or complex hydrocarbons; nutritionally very diverse.
Vibrio-*Aeromonas*	Soil, fresh and marine waters; some pathogens of fish and invertebrates.	Some species proteolytic and/or saccharolytic.

TABLE 10. Bacteria isolated at all stations during prethermal and thermal periods.

	Number & Percent of Isolates			
	Prethermal (65-67)		Thermal (68-69)	
Genus or Group	No.	%	No.	%
Achromobacter-*Alcaligenes*	53	37	37	27
Bacillus	10	7	9	7
Chromobacterium	0	0	1	1
Coryneforms	28	19	17	12
Enterobacteriaceae	8	6	22	16
Flavobacterium-*Cytophaga*	13	9	21	15
Micrococci	2	1	1	1
Pseudomonas	14	10	21	15
Spirillum	0	0	0	0
Vibrio-Aeromonas	10	7	9	7
Unidentified	7	5	0	0
Total number of isolates	145	(100%)	138	(100%)

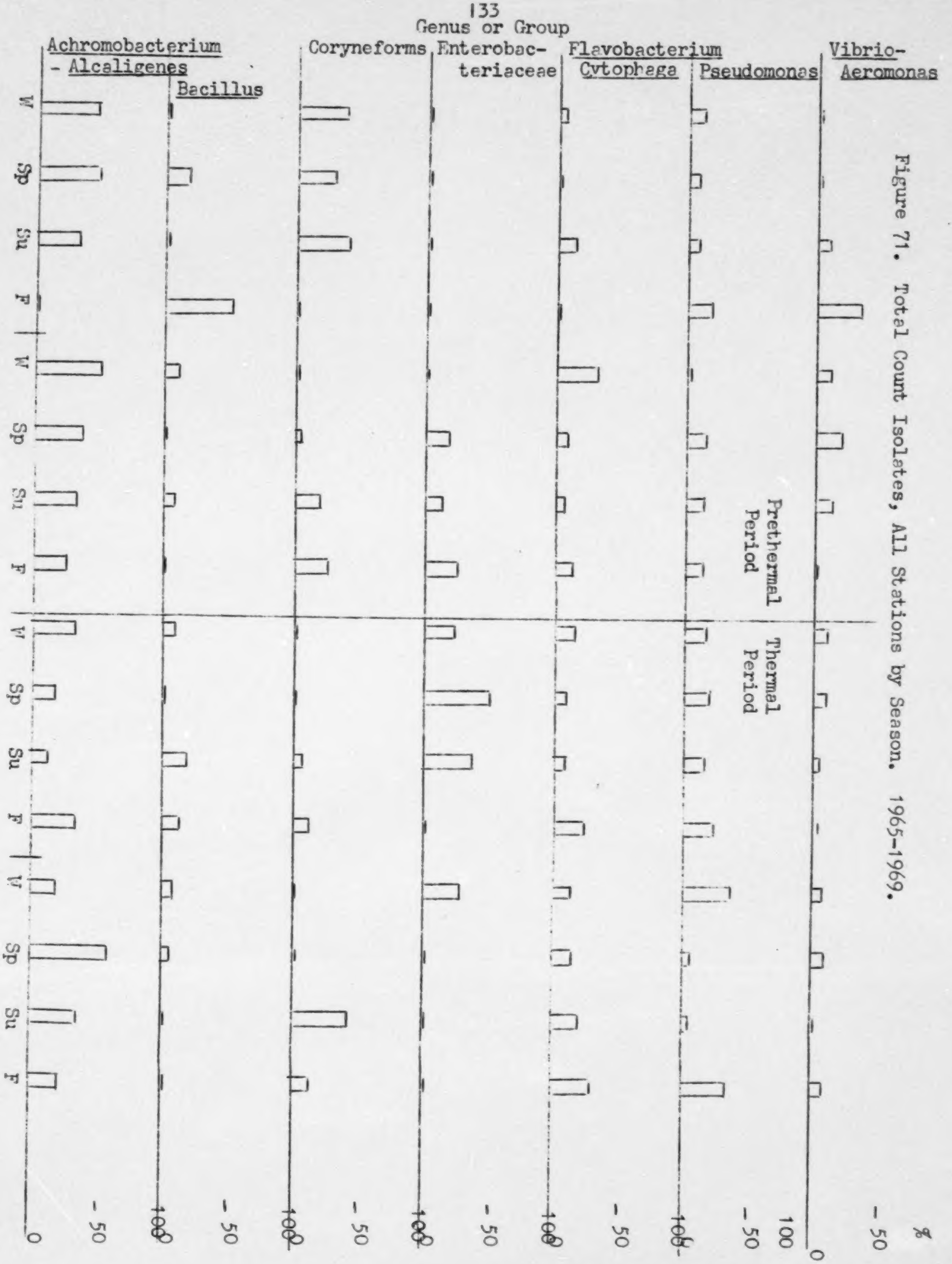


Figure 71. Total Count Isolates, All Stations by Season. 1965-1969.

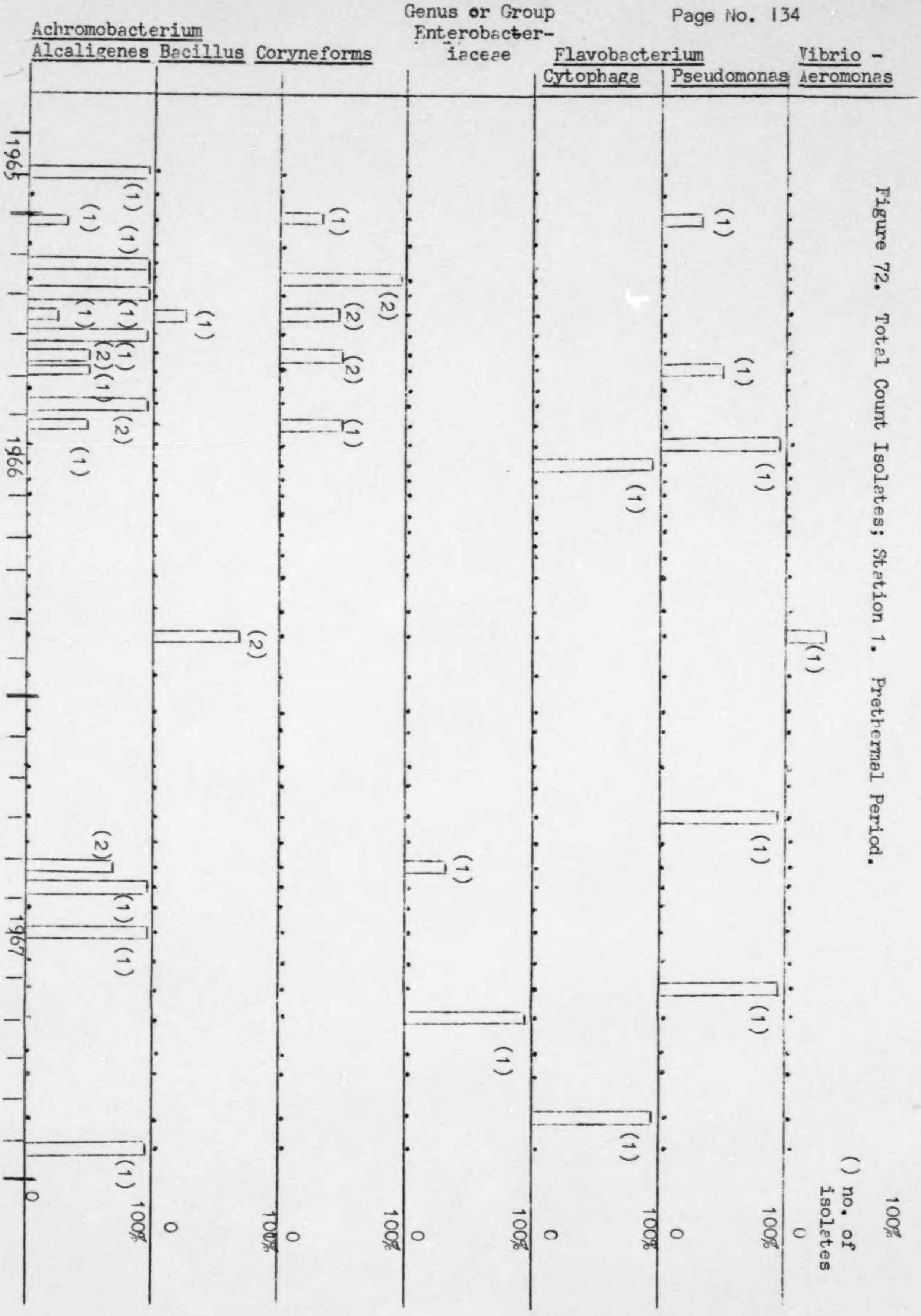


Figure 72. Total Count Isolates; Station 1. Prethermal Period.

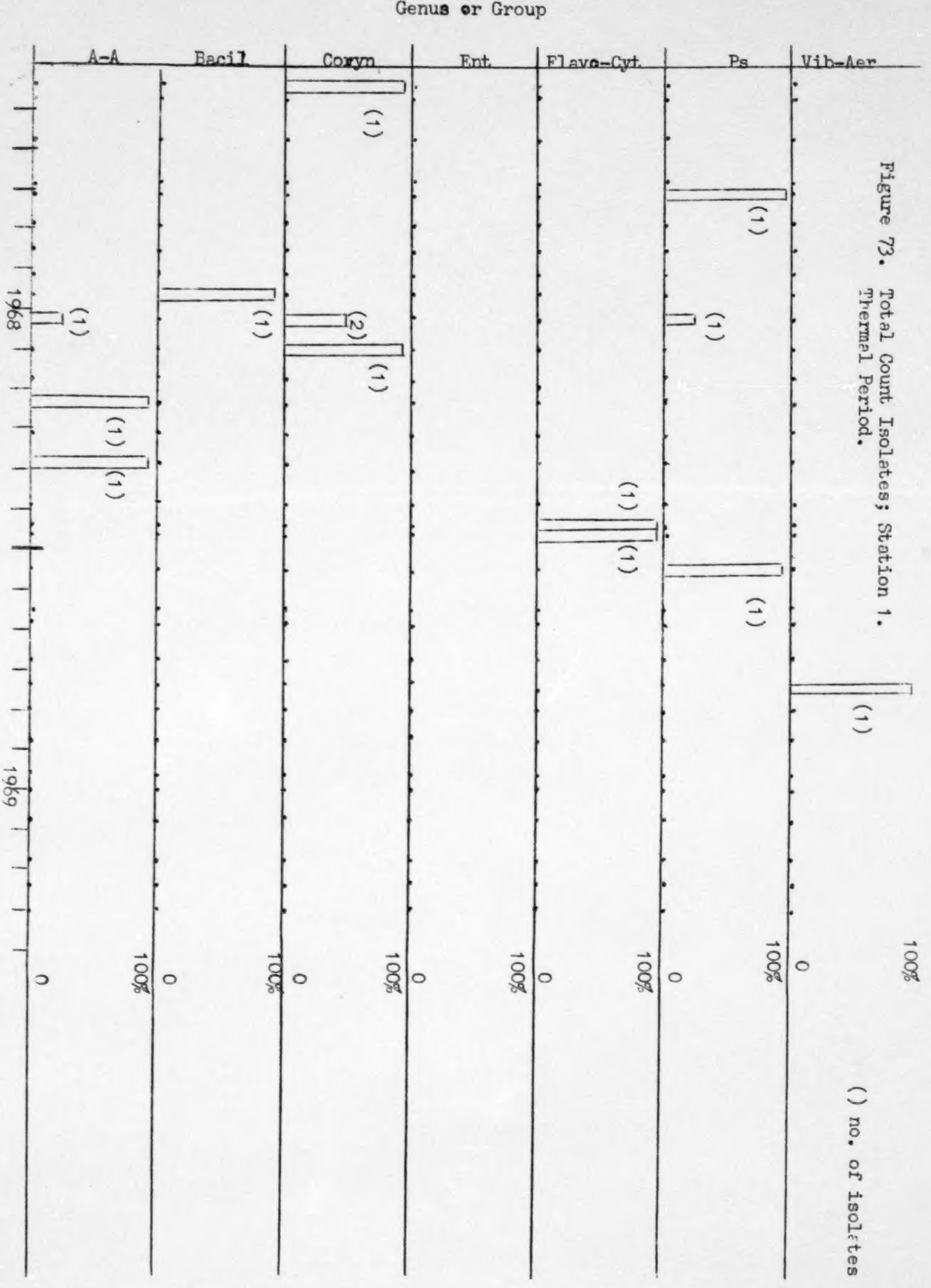


Figure 73. Total Count Isolates; Station 1. Thermal Period.

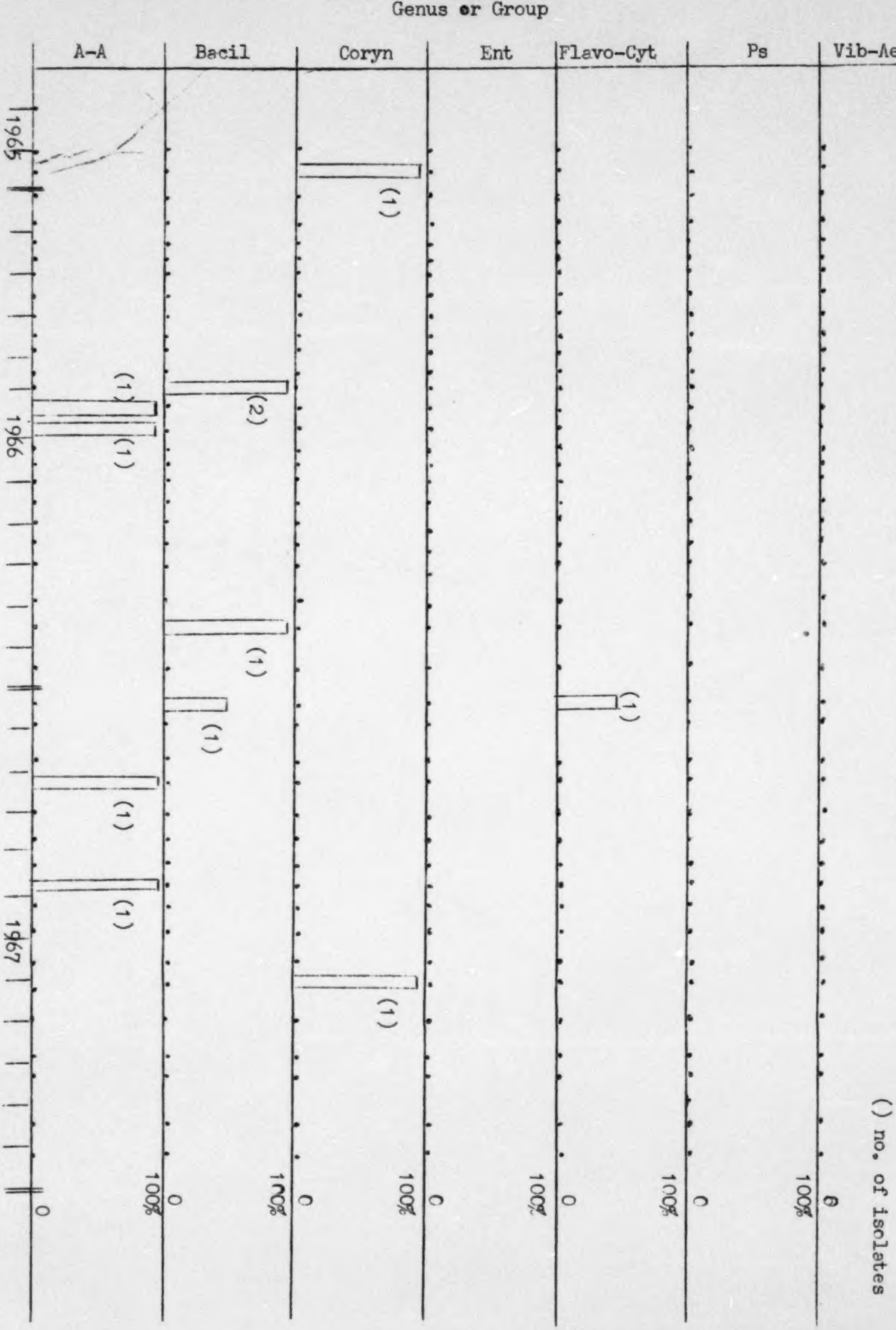


Figure 74. Total Count Isolates; Station 3T. Prethermal Period.

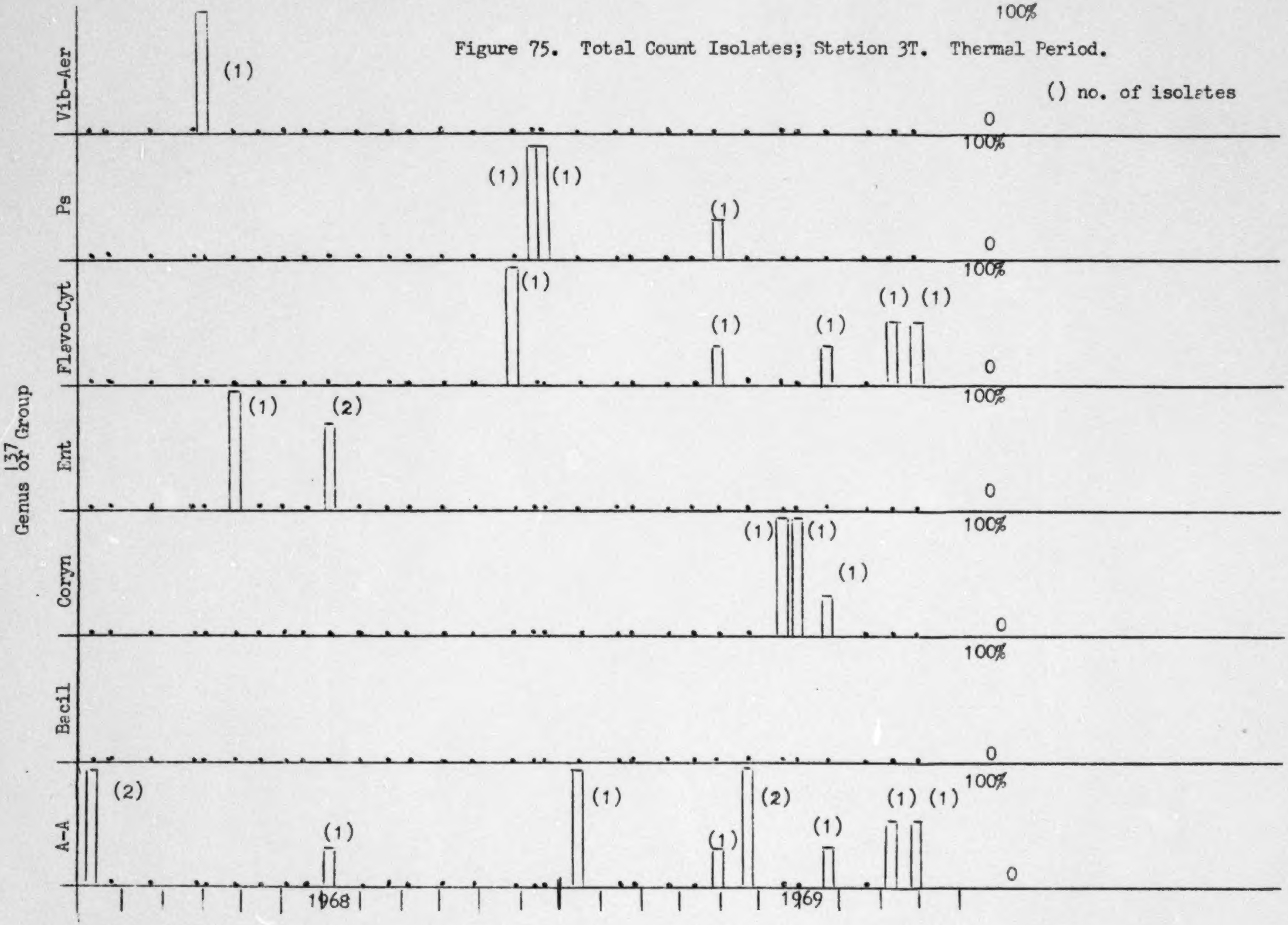


Figure 75. Total Count Isolates; Station 3T. Thermal Period.

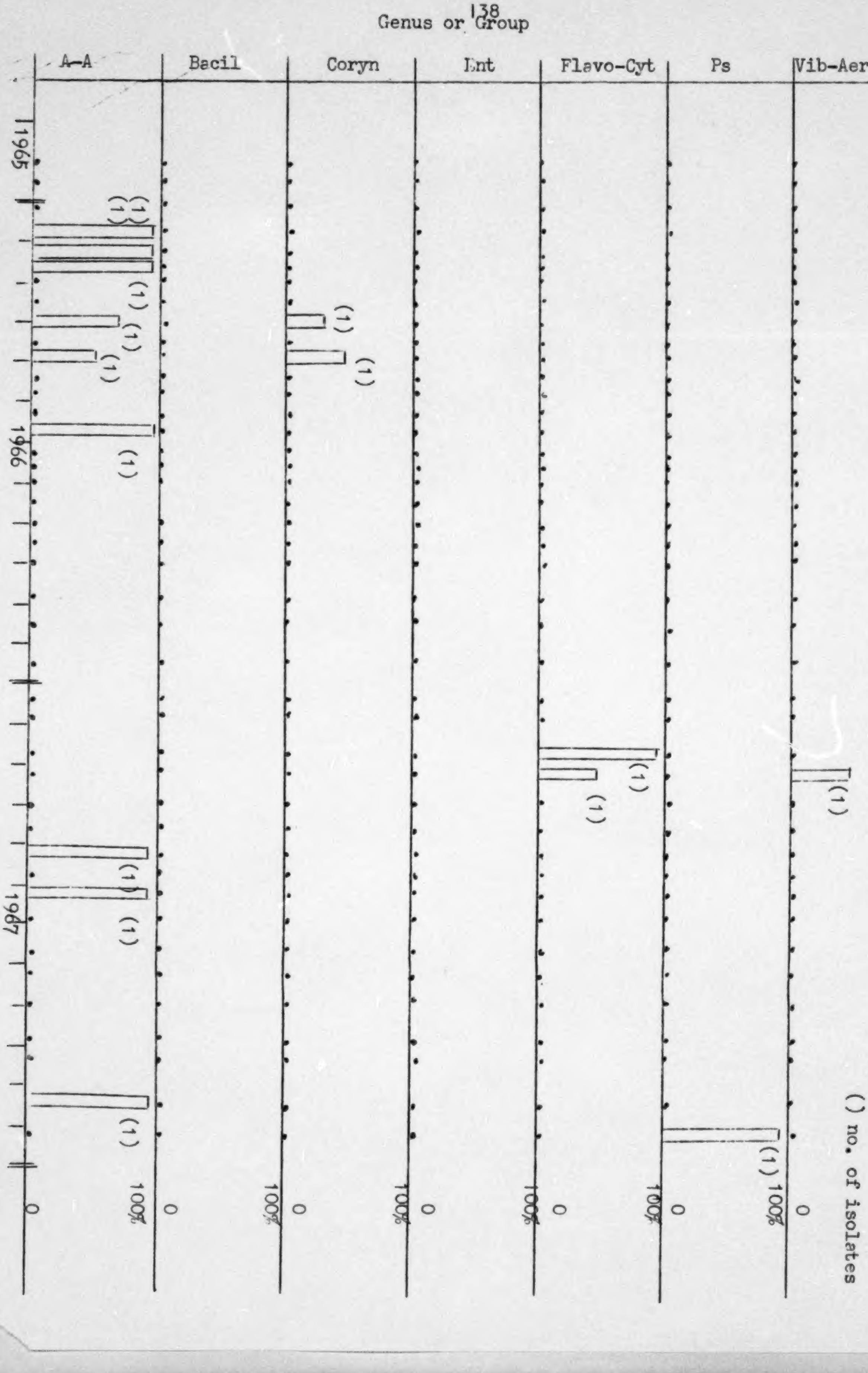


Figure 76. Total Count Isolates; Station 3B. Prethermal Period.

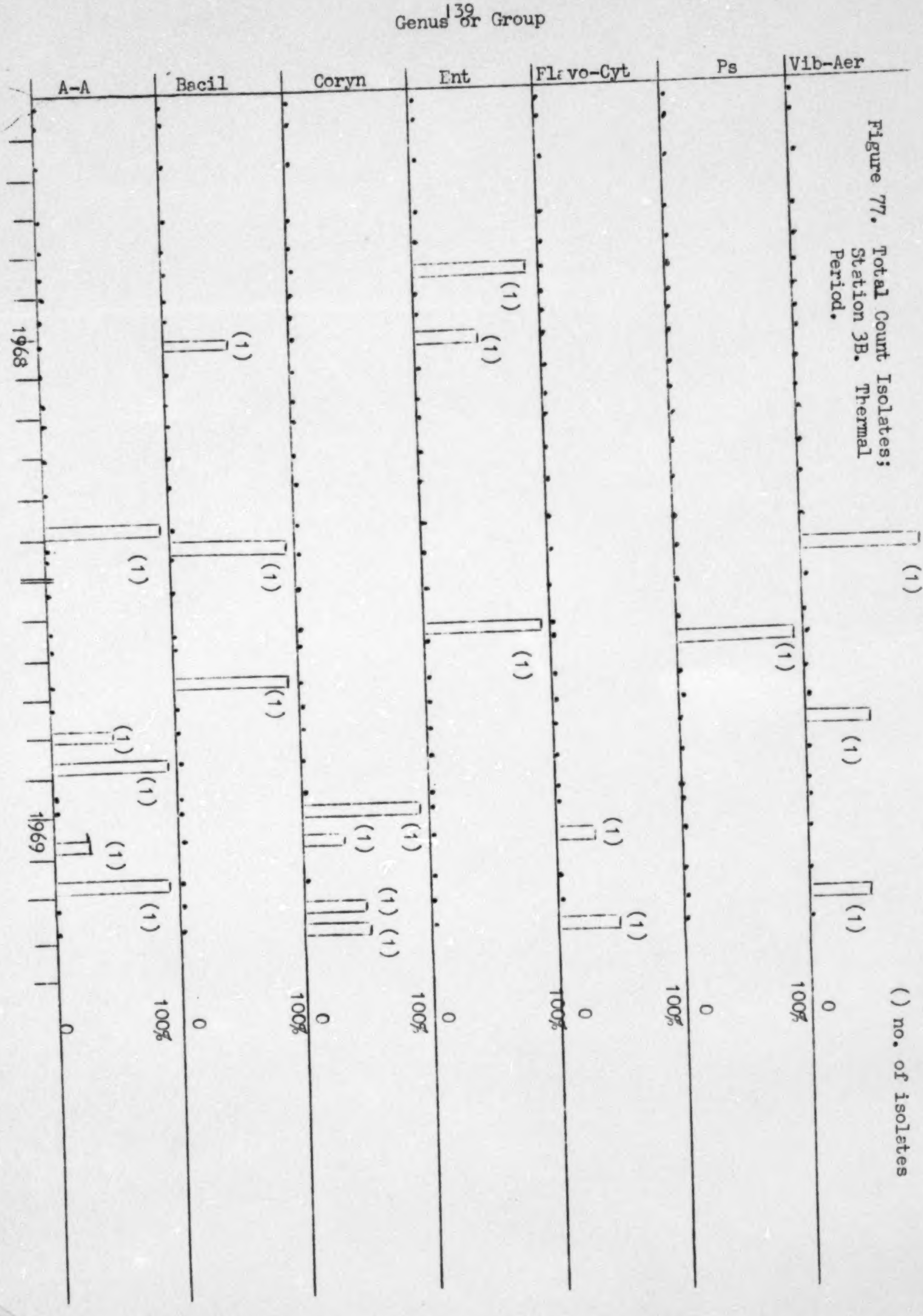


Figure 77. Total Count Isolates; Station 3B. Thermal Period.

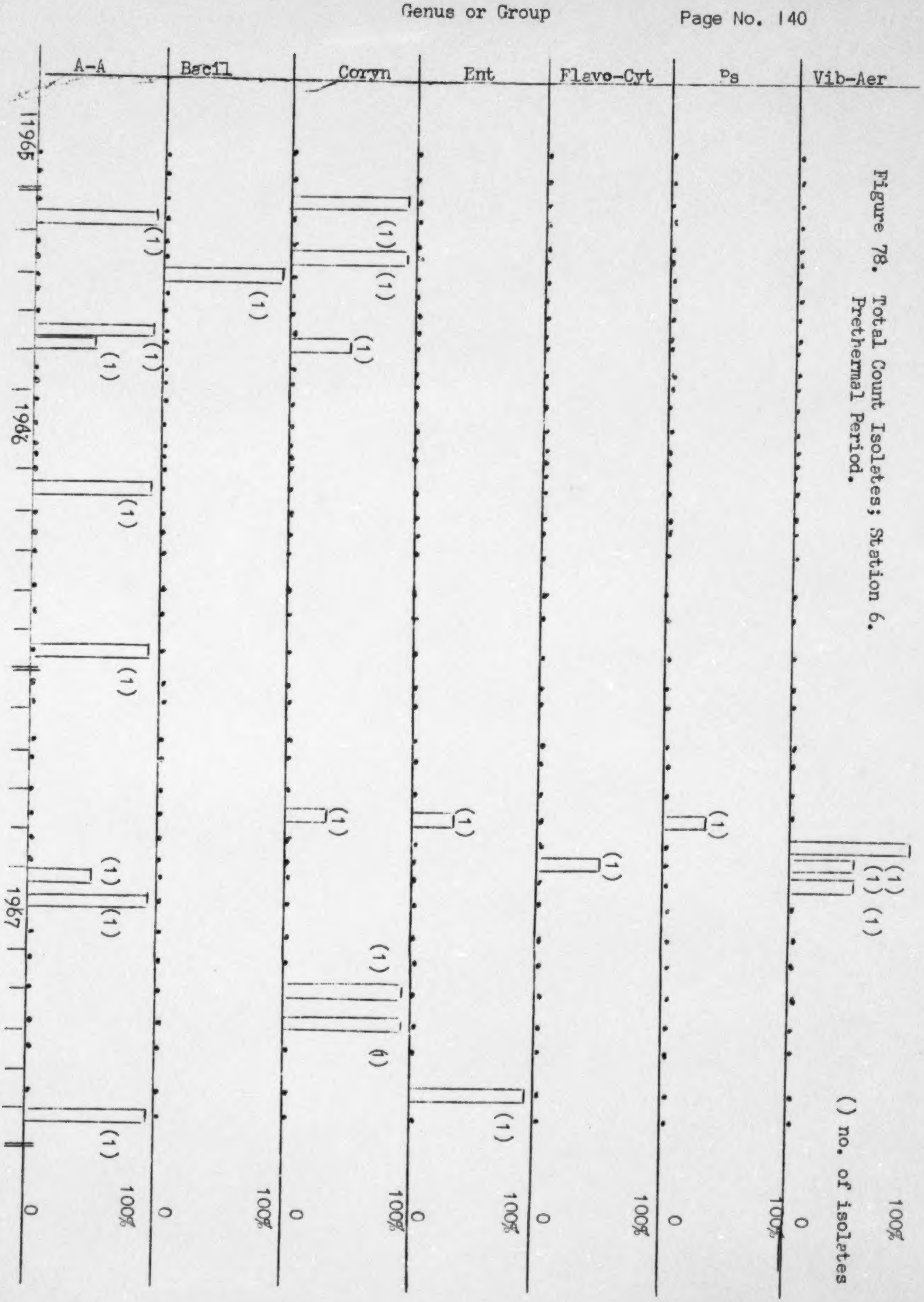


Figure 78. Total Count Isoletes; Station 6.
Prethermal Period.

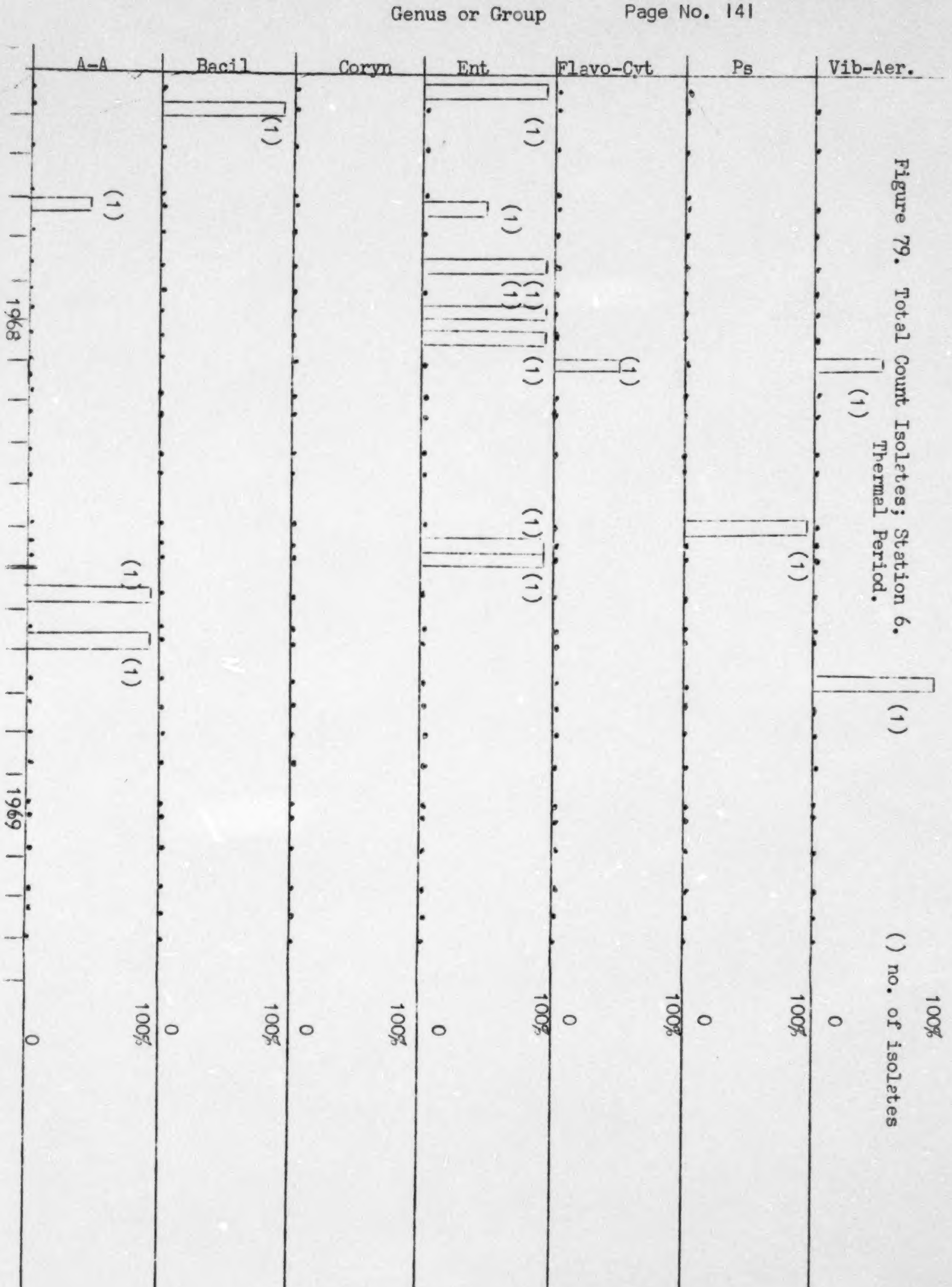


Figure 79. Total Count Isolates; Station 6. Thermal Period.

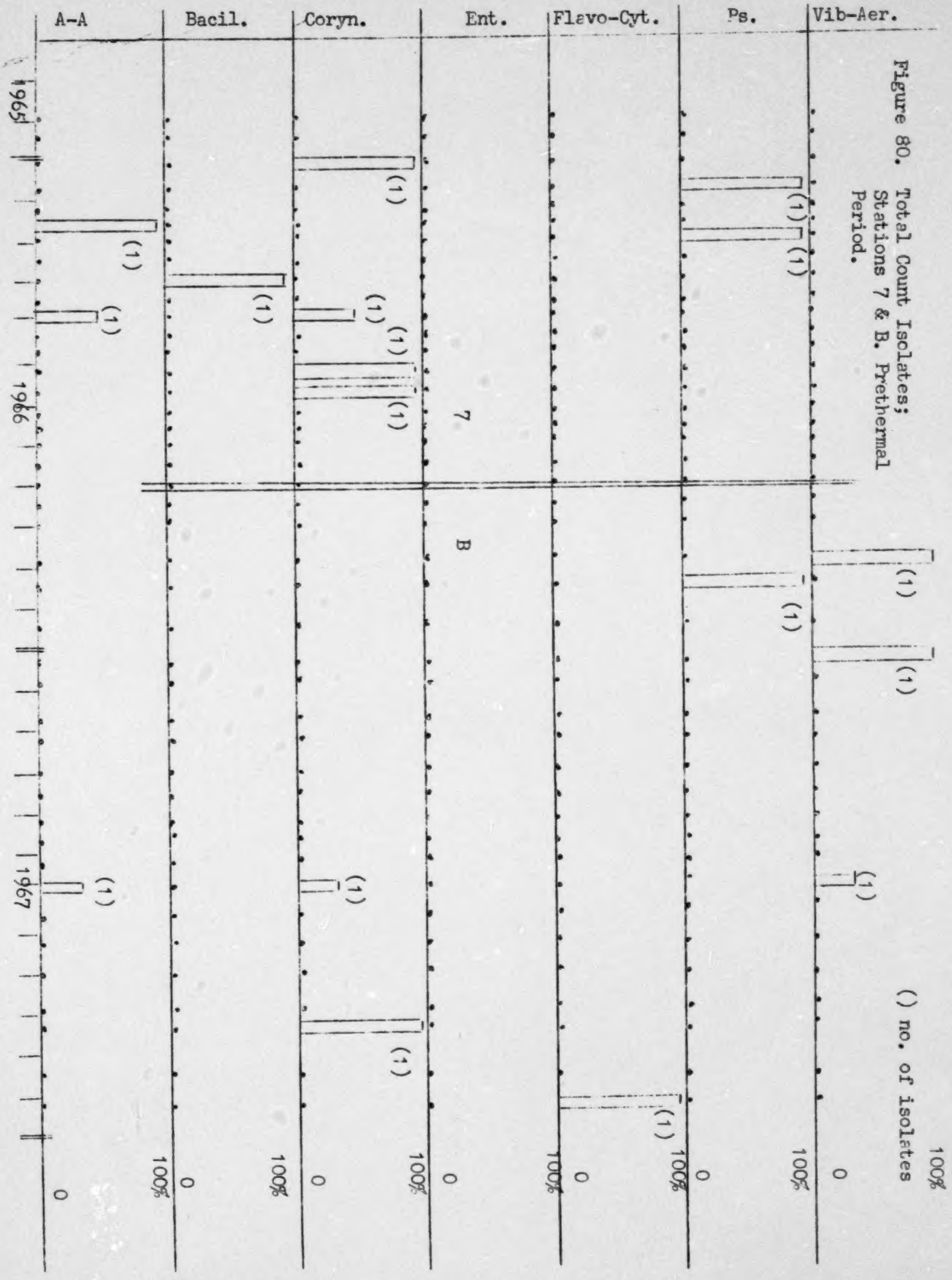


Figure 80. Total Count Isolates; Stations 7 & B. Prethermal Period.

( ) no. of isolates

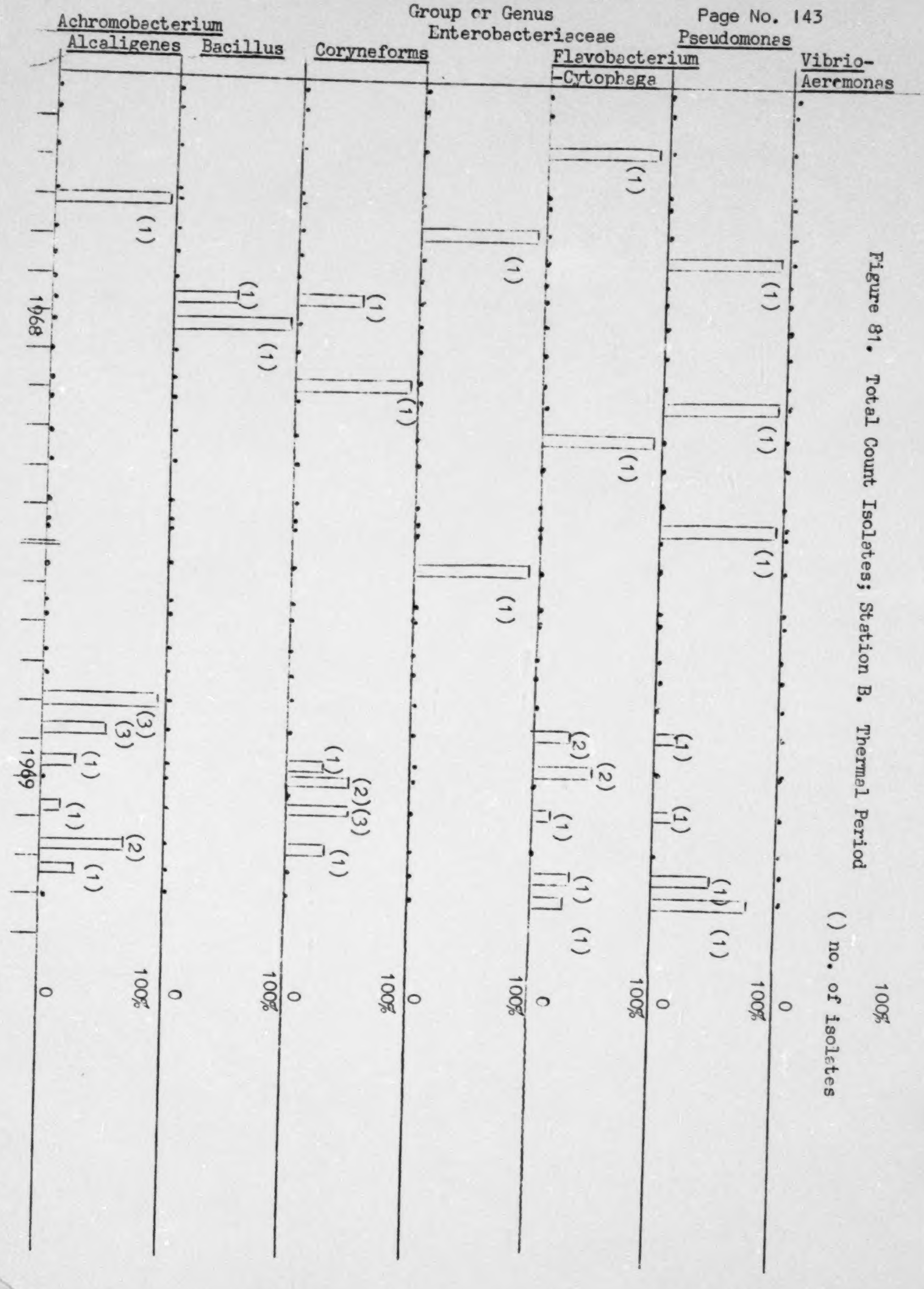


Figure 81. Total Count Isolates; Station B. Thermal Period

Station 3, top and bottom, is evaluated again in Table 11. In comparing these observations to the overall River picture (Table 10) in prethermal and thermal periods, we may make the following generalizations: (1) some differences were noted between 3T and 3B waters during the thermal period; the frequency of occurrence of *Achromobacter-Alcaligenes* increased while decreasing in the overall data, *Pseudomonas* species decreased at 3T during the thermal period but increased overall, and the *Vibrio-Aeromonas* group decreased as thermal effluent was added while remaining constant in the composite data, (2) the coryneforms increased at both 3T and 3B while decreasing overall, (3) the *Flavobacterium-Cytophaga* complex increased at both Station 3 and at all stations and (4) the Enterobacteriaceae decreased in frequency at Station 3 top and bottom but increased in frequency in all station data.

These observations seem to indicate that thermal effluent may be selecting (stimulating? supporting?) the *Achromobacter-Alcaligenes* and coryneform bacteria while suppressing the *Vibrio-aeromonas* group and the enteric bacteria.

2. Chemostat studies on unsupplemented river water. In an attempt to expand upon the possible role of temperature as an environmental selection factor, we employed the chemostat technique in the laboratory. The details of these experiments, performed with Connecticut River water aseptically collected near the intake of the CYAPC plant on 20 August 1968, 26 February 1969, and 11 September 1969, have been described in detail (36,37). Briefly, the chemostat consists of a small growth vessel equipped with an overflow siphon and a device for the continuous delivery of fresh medium, in this case Connecticut River water. The chemostat is regulated to allow the slow introduction of water; for each drop that enters, a drop of culture (water) overflows out of the growth vessel. At the times when experiments were run,

TABLE II. Percentage distribution of bacterial groups at Station 3 (outfall area).

	Prethermal				Thermal			
	No.	%	No.	%	No.	%	No.	%
Genus or Group	3T	3T	3B	3B	3T	3T	3B	3B
Achrom-*Alc*.	6	27	10	43	7	46	7	38
Bacillus	4	18	3	13	0	0	1	6
Chromob.	0	0	0	0	0	0	0	0
Corynef.	2	9	2	9	3	20	4	22
Entero	2	9	2	9	0	0	1	6
Flavo-*Cyt*.	3	14	2	9	4	27	2	11
Micro	0	0	0	0	0	0	0	0
Pseudom.	3	14	1	4	1	7	1	6
Spiri	0	0	0	0	0	0	0	0
Vib-*Aer*	2	9	2	9	0	0	2	11
Unidentified	0	0	1	4	0	0	0	0
Total	22	(100)	23	(100)	15	(100)	18	(100)

two chemostats were used; one placed at ambient river temperature (control) and the other incubated at the temperature of thermal effluent. The devices were allowed to operate for 10 days, with samples removed daily and plated at various temperatures to determine whether or not incubation temperature of the chemostat had any selective effect on bacteria capable of developing at different temperatures. Bacteria were isolated from the various platings and identified as to genus or group.

We did not isolate any bacteria from any chemostats which were different from those present in the original inoculum of river water which contained all of the dominant organisms discussed above, except for coryneforms which were not encountered in chemostat samples. With respect to the generalizations advanced for Station 3 (area of thermal influence), chemostat data support our contention that the *Achromobacter-Alcaligenes* group may be encouraged by heated water and that the *Aeromonas-Vibrio* organisms decrease in the presence of thermal effluent. On the other hand, the genus *Pseudomonas* was isolated routinely from nearly all chemostat platings and the Enterobacteriaceae were common also. These findings were inconsistent with field data.

Our limited chemostat studies are significant to the point that they confirm the field observations that no drastic microbiological imbalance occurs in the presence of added heat, and they tend to support some assumptions regarding the selection of certain genera of bacteria. However, the chemostat experiments also indicate some microbial selections which were not shown in isolations from plating of river water itself.

For the purposes of discussion, let us assume that these laboratory studies can be extrapolated to the river environment, since the theory of chemostat operation is not unlike that which exists in the river itself. The Connecticut River is dynamic, as stream flow data indicate, and is receiving constant replenishment of nutrients as well as reinoculation of microorganisms from many sources; i.e., sewage, run-off, etc. From Table 9, it can be seen that suppression of Aeromonics-Vibrio bacteria would have probably little effect on the biochemical and mineralization (degradative) potential of a thermal environment since these organisms may be replaced by other groups, especially Pseudomonas which is in general biochemically more active.

Under the conditions of our study and our observations, we cannot conclude that any major microbial or biochemical alterations have occurred in the Connecticut River as a result of thermal effluent within the relatively short period of investigation. Any generic or group shifts as selections in bacteria at Station 3 which were noted or postulated as a result of field or laboratory studies cannot be unequivocally interpreted as either deleterious or beneficial at this time. We have no data to indicate any evidence of significant microbial imbalance in our sampling areas. It may be that samples taken in the outfall canal would show more striking quantitative and qualitative changes than we have been able to demonstrate. If so, these changes do not extend into our sampling area as yet and therefore cannot be interpreted presently as affecting the Connecticut River as an ecosystem.

3. Study of immediate waters entering and leaving the plant. Through the courtesy of the CYAPC, we were allowed to conduct a study of waters just entering and leaving the plant. Sampling from the plant itself, we collected Connecticut River water a few feet from the intake and effluent water a few feet after leaving the plant. These latter samples were taken before the water passed over an aeration weir and before entering the 600' long effluent canal. Our primary interest in this study was an evaluation of bacterial numbers as affected by passage through the CYAPC plant cooling system. Details of the operation are found in an earlier report (37). There was no significant difference in bacterial counts between intake and

outfall waters, except during the daily period of chlorination. At this time counts on effluent waters dropped to barely detectable levels but had increased to prior values at the next sampling. Considering that the residence time of a given "particle" of cooling water in the plant is about 1 1/2 minutes and attained condenser temperature of approximately 99° F (37°C) for a fraction of that period, it is not unusual that such conditions would have little effect on the genera of bacteria isolated commonly from the Connecticut River. We made a number of isolations from the platings above but the total number of organisms isolated was too small to allow any firm conclusions to be drawn. For example, no species of Aeromonas-Vibrio were detected in intake waters yet three isolates were found in effluent waters. It is most probable that the passage through the plant has minimal quantitative and qualitative influence on bacteria in river water; rather, any changes which may occur are a result of residence (transport) through the effluent canal which acts essentially as a constant temperature incubator. Temperature drop from one end of the canal to the other is only a matter of 2-3° F.

4. Temperature tolerance of "thermophilic" and "psychrophilic" isolates. During the course of our study, bacteria were isolated routinely from platings made at 5°, 45° and 55° C. Once established in pure culture, these isolates were incubated at 5, 15, 25, 35, 45 and 55° C for up to 10 days with visible growth checked periodically. Of the "thermophile" isolates (from 45° to 55° plates), a total of 178 isolates were cultured as above during the "before" portion of the study. Of these, a total of seven, or about 4%, grew only at 45° and/or 55° C and were properly classed as obligate thermophiles: one came from Station 3. All others grew only at temperatures below 45° C or below 45° C as well as at 45° or 55° C and were considered facultative thermophiles or mesophiles. After plant operation, seven of 133 isolates (5%) were shown to be obligate thermophiles and only one of these was isolated from Station 3 (outfall).

Isolates from "psychrophile" platings showed similar results. Prior to plant operation, 10% (10 of 102) of the isolates were obligate psychrophiles; i.e., grew only at 5° and/or 15° C. After CYAPC plant operation, 19 of 135 isolates (14%) showed a similar growth response.

5. Salinity tolerance of "marine" bacteria. Since our study area overlapped the uppermost area of salinity intrusion shown previously (53), we routinely plated samples of river water on a nutrient medium prepared with seawater. Bacteria were picked from these plates and observed for visible turbidity for one week in liquid media made with both seawater and distilled water. Over the entire study period, only 7 of 299 isolates, or 2%, grew only in seawater media.

These data, taken with the temperature studies above and the overall quantitative and qualitative observations on the various bacterial populations in the Connecticut River, indicate that these organisms represent a very adaptable segment of the ecosystem. We found little evidence for the occurrence of "obligate" bacteria in terms of temperature or salinity. None of the dominant genera isolated are characterized by extremely fastidious nutritional requirements. It seems likely that the effect of increased temperature alone is minimal on the general bacterial condition of the Connecticut River. Since summer ambient temperatures may approach 85° F or higher (around 30° C; a usual optimal temperature for many bacteria encountered here), an artificial increase to 100°F (38° C) cannot be predicted to decimate completely these organisms since this temperature is not considered as supraoptimal for bacterial culture.

The vast majority of bacteria in the Connecticut River are considered to be mesophiles; i.e., their optimal growth temperature is between 20° and 45° C. While considerable information is available on these organisms since they comprise most of the soil, water and pathogenic bacteria, we must distinguish here between "growth" of an organism and its mere survival. In terms of thermal effluent, it would seem that the latter is of more importance, since the total exposure time of a cell to thermal influence of the power plant is relatively short. Once a given volume of cooling water rejoins the river, the area of thermal influence is small and confined to the surface. Unless an organism remains in this heated area for a considerable period of time, it is unlikely that either death or multiplication to any extent will occur. If the power plant were located on a lake or semi-enclosed body of water, then the thermal effect could be enhanced by a bacterium being entrained in heated water for an extended period of time with attendent adaptive situations developing. Even this may require some time and many mesophiles do not give rise easily to thermophilic variants (85). A potentially more significant yet poorly understood phenomenon is bacterial response to certain specific temperatures, probably related to physical-chemical structures of the water molecule at these temperatures (86). Alternating power levels in a generating plant will produce fluctuations in temperature of effluent. This may be also a "triggering" stimulus for biological activity by either stimulation or inhibition. Again, effects may be mimimal and/or confined to immediate outfall areas such as an effluent canal.

6. Biochemical characteristics of pollution-indicating bacteria.

During the first year of the study, most probable number (MPN) determinations of total coliforms were made in lactose broth as well as membrane filter platings. Of 552 positive lactose tubes, 275 (49%) were confirmed as containing fecal coliforms by the elevated temperature EC test. Colonies from membrane filter plates were tested similarly, with 34% showing a positive EC test. Only 21% of the isolates were confirmed as _Escherichia coli_ by IMViC reactions.

Commencing in August 1966, membrane filter platings were cultured also at 44.5° C. Colonies (554) picked from the platings were confirmed both by the EC test and IMViC reactions. Results were as follows: 99% (547) were of fecal origin (EC positive); 99% were lactose positive and 89% (494) were typical of *E. coli* IMViC results (++-- and -+--). Five other IMViC types were recovered also.

After the first year, MPN counts were discontinued with membrane filter platings retained for total coliform counts. Isolates from these plates (703) during the remainder of the study were characterized also by the EC and IMViC tests. Of the 703 cultures, 25% were of fecal origin by the EC test and 90% (632) were lactose positive but only 13% (94) were confirmed as *E. coli* by IMViC reactions. In all, fourteen different IMViC types were recovered (Table 12). The most frequent (38%) was --++, which is characteristic of *Aerobacter aerogenes*, a common soil bacterium. Another 16% (109) were -+-+, generally considered typical of intermediate soil organisms.

Enterococci were estimated initially by the MPN procedure using azide dextrose broth. In August 1966, this procedure was discontinued in favor of the membrane filter method. Colonies from these platings were examined further by culture in azide dextrose and ethyl violet azide broths as well as by periodic microscopic examination. All isolates chosen were confirmed as streptococci. Related studies on marine and estuarine areas were not as successful (44).

TABLE 12. IMViC characteristics of total and fecal coliform plate isolates.

Total Coliform Isolates:

IMViC Type	Number	%
--++	292	42
-+-+	109	16
++--	85	12
++++	53	8
-+++	53	8
++-+	44	6
+-++	34	5
-+--	9	1
---+	7	1
+++-	7	1
-++-	4	0.5
----	2	0.3
--+-	2	0.3
+-+-	2	0.3
	703	

Fecal Coliform Isolates:

IMViC Type	Number	%
++--	485	88
--++	28	5
++-+	27	5
-+--	9	2
++++	2	0.4
+-++	2	0.4
-+++	1	0.2
	554	

VII. Summary of Allied Research - Essex Marine Laboratory

On 19 October 1964, the State of Connecticut Water Resources Commission published its findings in regard to the application of the Conn. Yankee Atomic Power Company. In brief, the WRC ordered that a permit be issued for the work as requested and that a comprehensive river study be initiated. The Essex (Conn.) Marine Laboratory, under support from the CYAPC, has been studying various aspects of the hydrology and biology of the Connecticut River. The most recent semiannual progress report (17) of The Connecticut River Investigation, under the direction of Dr. Daniel Merriman of Yale University, summarizes its findings as follows:

(1) The mouth of the discharge canal, which was designed to reduce velocity and promote maximum flotation of the heated plume of water works about as predicted. The plume shifts with wind and tide, often reaching the opposite shore, but it does not penetrate to any great depth. There is always a substantial passageway of unheated water for fish movement. On rare occasions, there is a minimal recirculation of water at about the 1° F level.

(2). Benthic organisms have shown quick response to the operation of the plant and there have been dramatic changes in both quantity and diversity on some sampling stations. Some areas show decreased, others increased production. Current studies should allow some estimation on whether the changes in the bottom fauna represent a true loss or gain to the fish population.

(3) Young shad seem to have no difficulty in passing the plant site on their way to the sea. A minor amount of shad spawning occurs in the general vicinity and some eggs, and perhaps some larvae, are pulled into the plant intake. Their fate is not known although river herring apparently are not destroyed by this experience. It seems clear that the number of

shad eggs and larvae which go through the plant is so low that their loss could not affect the shad population to any measurable degree.

(4) There is an unexpectedly large fish concentration in the discharge canal during the cold months and a deterioration of their physical condition as time progresses. However, they do not die as the result of prolonged exposure to the heated water. They leave the canal and tagging results show they then travel considerable distances.

(5) Creel census results show that sport fishing in the general area has remained quite stable following plant operation. There is some indication that a school striped bass fishery may be developing in and adjacent to the lower end of the discharge canal.

(6) Tag returns indicate no significant interruption of upstream movement of the spawning run of adult shad.

This report summarizes the overall findings by the following: "With no attempt to anticipate a final conclusion, it is accurate to report that, as of this time, no instance of significant damage to the biota has appeared".

VIII. Evaluation of study

The purpose of this study was to evaluate the effects, if any, of thermal discharge on the microbiology and chemistry of an area of the Connecticut River. In order to accomplish this, a number of somewhat subjective decisions were made; frequency of sampling, microorganisms to seek both quantitatively and qualitatively, chemical determinations to make (which ones and how) and many related factors. In setting up such a regimen, the risk is always present that errors in judgement become evident at a later date, perhaps too late to allow a new start. The investigator essentially has only one opportunity.

Our data represent approximately 27 months of "before" observations and 21 months of postoperative activity. Ideally, we consider these periods inadequate for a valid assessment of thermal effects, particularly in regard to evaluation of prethermal, "normal" conditions. Since one abnormal year (e.g., drought, heavy prolonged precipitation) could easily affect the overall "before" observations with which all "after" data will be compared, the prethermal study period becomes critical. We have indicated in several cases that our baseline data may have been influenced by climatological factors. While we are somewhat uncertain about the significance of these possible anomalies, our overall estimation of prethermal observations is that they probably represent the general trend of environmental characteristics. With this in mind, we strongly urge that future studies consider preoperational conditions over a longer period than two years. The obvious counter to this proposal is the question of just how long a study is adequate since funding, prior knowledge of industrial intent, personnel, etc. may be limiting. Our response would be to study an area intensively for as long as possible both before and after the activity in question but for a minimum of a total of four full years.

Considering the logistics of field sampling, the two or three week intervals between collections reported here are considered adequate although more frequent trips are highly desirable.

We advocate the use of constant recording devices, particularly for monitoring parameters affected by biological activity (e.g. dissolved oxygen).

Except as noted above, all sampling techniques and laboratory procedures remained constant during the study period so that our data are comparable for all periods of collection.

In summary, we are confident that our approach to the problem was sound. Obviously, our conclusions must be prefaced with a consideration of the kinds of observations made and the period during which they were made, which we feel was minimal. It may be that some biological and/or chemical features not studied may have been significantly altered by thermal addition and may not be reflected in the overall ecology for a long period of time. We believe that an additional identical study of at least a year duration should be made within the next five years to confirm our initial thermal period observations. Similar reevaluations could be made at 10 and 20 year intervals also. In addition, studies on habitat recovery should be instituted as soon as a plant ceases activity on a permanent basis or for a period of more than a few months.

References

1. Philips, O.M. et al. 1970. Nuclear power plants and our enviornment. A report to the Maryland Academy of Sciences by the Study Panel on nuclear power plants. Maryland Acad. of Sci., Baltimore, Md.

2. Clark, J.R. 1969. Thermal pollution and aquatic life. Sci. Amer. 220(3): 19-27.

3. Public Act No. 57. An act concerning the elimination of pollution of the waters of the State, 1967 session, Connecticut General Assembly. Available from Commissioner, Dept. of Agric. and Nat. Res., State Office Bldg., Hartford, Conn. 06115.

4. Jones, J.R.E. 1964. Fish and river pollution. Butterworth and Co., London.

5. Rose, A.H. (ed.) 1967. Thermobiology. Academic Press, New York, New York.

6. Klein, L. 1962. River pollution. 2: Causes and effects. Butterworth and Co., London.

7. Naylor, E. 1965. Effects of heated effluents upon marine and estuarine organisms. Adv. Mar. Biol. 3:63-103.

8. FWPCA, Technical Advisory and Investigations Branch. 1967. Temperature and aquatic life. Laboratory Investigations, Series 6. FWPCA, Cincinnati, Ohio.

9. Wurtz, C.B. and C.E. Renn. 1965. Water temperatures and aquatic life. Edison Electric Institute Res. Proj. No. 49, Edison Electric Institute, New York, New York.

10. Ecology Section, Battelle Memorial Institute. 1968. Biological effects of thermal discharges: Annual Progress Report for 1967, Vol. I: Biological Sciences. Battelle Mem. Inst., Pacific Northwest Lab., Richland, Wash. 99352.

11. Coutant, C.C. 1969. Thermal pollution-biological effects; a review of the literature of 1968. Battelle Mem. Inst., Pacific Northwest Lab., Richland, Wash. 99352.

12. Coutant, C.C. 1970. Thermal pollution-biological effects; a review of the literature of 1969. Battelle Mem. Inst., Pacific Northwest Lab., Richland, Wash. 99352.

13. Katz, M. et al. 1967. "Biology" in a review of the literature of 1966 on wastewater and water pollution control. The Research Committee, Water Pollution Control Federation.

14. Kennedy, V.S. and J.A. Mihursky. 1967. Bibliography on the effects of temperature in the aquatic environment. Contrib. No. 326, Univ. of Maryland Natural Res. Instit.

15. Raney, E.C. and B.W. Menzel. 1969. Heated effluents and effects on aquatic life with emphasis on fishes. Cornell Univ. Water Resources and Marine Science Center, Philadelphia Electric Co. and Ichthyological Assoc.

16. FWPCA, Delaware Estuary Comprehensive Study Staff. 1966. Delaware Estuary Comprehensive study. FWPCA, Philadelphia, Pa.

17. Sundaram, T.R. et al. 1969. An investigation of the physical effects of thermal discharges into Cayuga Lake (Analytical study). Final Report, CAL Rept. No. VT-2616-0-2. Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y. 14221.

18. Merriman, D. et al. 1969. The Connecticut River Investigation, 9th semiannual progress rept. Conn. Yankee Atomic Power Co., East Haddam, Conn.

19. Merriman, D. 1970. The calefaction of a river. Sci. Amer. 225 (5):42-52.

20. Mihursky, J.A. 1969. Patuxent thermal studies; Summary and recommendations. N.R.I. Spec. Rept. No. 1, Univ. of Maryland.

21. Adams, J.R. 1968. Thermal effects and other considerations at steam electric plants; survey of studies in the marine environment. Rept. No. 6934.4-68, Pacific Gas & Elec. Co., Dept. of Engineering Research.

22. Anon. 1969. A summary of environmental studies on water problems by investor-owned electric utility companies recently completed, underway, and proposed. Edison Electric Institute, New York, New York.

23. Krenkel, P.A. and F.L. Parker (eds.). 1969. Biological aspects of thermal pollution. Proc. Nat. Symp. on Thermal Poll., Portland, Ore. 3-5 June 1968. Vanderbilt Univ. Press, Nashville, Tenn.

24. Parker, F.L. and P.A. Krenkel (eds.). 1969. Engineering aspects of thermal pollution. Proc. Nat. Symp. on Thermal Poll., Nashville, Tenn. 14-16 Aug. 1968. Vanderbilt Univ. Press, Nashville, Tenn.

25. Mihursky, J.A. and J.B. Pearce (co-chairmen). 1970. Proc. of the second Thermal Workshop, U.S.I.B.P. Ches. Sci. 10(3-4):125-341.

26. U.S. Dept. of the Interior, Bureau of Outdoor Recreation. 1968. New England heritage; the Connecticut River National Recreational Area study. U.S. Dept. of the Interior, Wash., D.C. 20240.

27. U.S. Dept. of Health, Education, and Welfare, Public Health Service. 1963. Proc. of a Conference in the matter of pollution of the interstate waters of the Conn. River, Hartford, Conn., 2 Oct. 1963. U.S. Dept. of HEW, PHS, Wash., D.C. 20201.

28. Van Dorn, W.G. 1956. Large volume water samplers. Trans. Am. Geophys. Union 37:682-684.

29. Niskin, S.J. 1962. A water sampler for microbiological studies. Deep-Sea Res. 9:501-503.

30. Postgate, J.R. 1963. Versatile medium for the enumeration of sulfate-reducing bacteria. Appl. Microbiol. 11:265-267.

31. APHA, AWWA and WCCF. 1965. Standard methods for the examination of water and wastewater (12th ed.). Amer. Pub. Health Assoc., Inc., New York, New York.

32. Strickland, J.D.H. and T.R. Parsons. 1965. A manual of sea water analysis. Bull. No. 125, Fisheries Res. Bd. of Can. (2nd ed.).

33. UNESCO. 1966. Determination of photosynthetic pigments in sea-water. Monogr. No. I on Oceanographic Methodology, Paris.

34. Trainor, F.R. and J.D. Buck. 4 Dec. 1966. Final report, PHS Contract No. Ph-86-66-19, Connecticut River Microbiology. Univ. of Conn. Marine Res. Lab., Noank, Conn.

35. Buck, J.D. 27 March 1968. Final report, FWPCA Contract No. 14-12-36, Connecticut River Microbiology. Univ. of Conn. Marine Res. Lab., Noank, Conn.

36. Buck, J. D. 25 Apr. 1969. Final report, FWPCA Contract No. 14-12-177, Connecticut River Microbiology, Univ. of Conn. Marine Res. Lab., Noank, Conn.

37. Buck, J.D. 30 Oct. 1969. Final report, FWPCA Contract No. 14-12-177, Connecticut River Microbiology. Univ. of Conn. Marine Res. Lab., Noank, Conn.

38. Foerster, J.W. 1969. A phyco-periphyton collector. Turtox News 47(3): 82-84.

39. Buck, J.D. and R.C. Cleverdon. 1960. The spread plate as a method for the enumeration of marine bacteria. Limnol. Oceanogr. 5:78-80.

40. Kadota, H. 1956. Microbiological studies on the weakening of netting cords. I. On the aerobic cellulose-decomposing bacteria in sea-water. Bull. Mem. Coll. Agric., Kyoto Univ., 72:63-70.

41. Starr, M.P. 1941. Spirit blue agar: a medium for the detection of lipolytic microorganisms. Science 93:333-334.

42. Geldreich, E.E. *et al*. 1965. Fecal-coliform-organism medium for the membrane filter technique. J. Amer. Wat. Works Assoc. 57:208-214.

43. Slanetz, L.W. and C.H. Bartley. 1957. Numbers of enterococci in water, sewage, and feces determined by the membrane filter technique with an improved medium. J. Bacteriol. 74:591-595.

44. Buck, J.D. 1969. Occurrence of false-positive most probable number tests for fecal streptococci in marine waters. Appl. Microbiol. 18(4): 562-565.

45. Leifson, E. 1960. Atlas of bacterial flagellation. Academic Press, New York, New York.

46. Hugh, R. and E. Leifson. 1953. The taxonomic significance of fermentative versus oxidative metabolism of carbohydrates by various Gram-negative bacteria. J. Bacteria. 66:24-26.

47. Kovacs, N. 1956. Identification of *Pseudomonas pyocyanea* by the oxidase reaction. Nature. 178:703.

48. Shewan, J.M. *et al.* 1960. A determinative scheme for the identification of certain genera of gram-negative bacteria, with special reference to the Pseudomonadaceae. J. Appl. Bacteriol. 23:379-390.

49. Hendrie, M.S. and J.M. Shewan. 1966. The identification of certain *Pseudomonas* species. In: Identification methods for micro-biologists, Part A. Academic Press, New York, New York.

50. Perry, C.A. and A.A. Hajna. 1944. Further evaluation of EC medium for the isolation of coliform bacteria and *Escherichia coli*. Amer. J. Pub. Health 34:735-739.

51. Ahearn, D.G. *et al.* 1962. A comparative study of marine and terrestrial strains of *Rhodotorula*. Can. J. Microbiol. 8:121-132.

52. Mackenthun, K.M. and W.M. Ingram. 1967. Biological associated problems in freshwater environments; their identification, investigation and control. USDI, FWPCA, Washington, D.C.

53. Meade, R.H. 1966. Salinity variations in the Connecticut River. Water Resources Res. 2(3):567-579.

54. Chittenden, M.E., Jr., and J.R. Westman. 1967. Highlights of the life history of the American shad in the Delaware River. Paper presented at public hearing on water quality standards for the Delaware River, Trenton, N.J., 26 Jan., Del. R. Basin Comm.

55. Howells, G.P. *et al.* 1970. Water quality in industrail areas: profile of a river. Env. Sci. & Technol. 4(1):26-35.

56. Patrick, R. and C.W. Reimer. 1966. The diatoms of the United States. Vol. I. Academy of Natural Sciences of Philadelphia Monograph #B.

57. Tiffany, L.H. and M.E. Britton. 1952. The Algae of Illinois. University of Chicago Press, Chicago.

58. Hohn, M.H. and J. Hellerman. 1963. The taxonomy and structure of diatom populations from three eastern North American Rivers using three sampling methods. Trans. Amer. Micros. Soc. 83:250-329.

59. Desikachary, T.V. 1959. Cyanophyta. Indian Council of Agricultural Research. New Delhi.

60. Prescott, G.W. 1962. Algae of the western Great Lakes Area. W.C. Brown Co., Des Moines.

61. Weber, C.I. 1966. A guide to the common diatoms at water pollution surveillance system stations. U.S. Dept. of the Interior, FWPCA, Cincinatti.

62. Ostle, B. 1963. Statistics in research, 2nd ed. The Iowa State University Press, Ames, Iowa.

63. Jaccard, P. 1902. Gesetze der Pflanzenvertherlung in der Alpinen Region. Flora 90:349-377.

64. Koch, L.F. 1957. Index of biotal dispersity. Ecology 38:145-148.

65. Lackey, J.B. 1949. Plankton as related to nuisance conditions in surface water. In: Limnological aspects of water supply and waste disposal. AAAS, Washington, D.C.

66. Mackenthun, K.M. 1969. The practice of water pollution biology. Supt. of Documents, Washington, D.C.

67. Appourchaux, M. 1952. Effets de la temperature de l'eau sur la faune et la flore aquatiques. L'Eau 8:377.

68. Trembly, F.J. 1965. Effects of cooling water from steam electric power plants on stream biota. In: Biological Problems in Water Pollution, pp. 334-335. U.S. Dept. of Health, Educ. and Welfare 992. Washington, D.C.

69. Dryer, W. and N.G. Benson. 1957. Observations on the influence of the new Johnsonville steam plant on fish and plankton populations. Proc. Ann. Conf. S.E. Assoc. Game and Fish Comm. 10:85-91.

70. Patrick, R. 1969. Some effects of temperature on freshwater algae. In: Biological aspects of thermal pollution, pp. 161-185. Vanderbilt Univ. Press, Nashville.

71. Brown, S.D. 1969. Grouping plankton samples by numerical analyses. Hydrobiol. 33:289-301.

72. Slack, K.V. and F.E. Clarke. 1965. Patterns in dissolved oxygen in a thermally loaded reach of the Susquehanna River, Penna. Geol. Surv. Prof. Pap. 525-C:C193-195.

73. Gorha, P.R. 1964. Toxic algae as a public health hazard. J. Amer. Wat. Works Assoc. 56:1481-1488.

75. Pacha, R.E. and E.J. Ordal. 1962. Columnaris disease in Columbia River salmon. Bacterol. Proc., pg. 20.

76. Wuhrman, K. 1964. River bacteriology and the role of bacteria in self-purification of waters. In: Principles and applications in aquatic microbiology (H. Heukelekian and N.C. Dondero, eds.). John Wiley & Sons, Inc., New York, N.Y.

77. Morrison, S.M. and J.F. Fair. 1966. Influence of environment on stream microbial dynamics. Hydrology paper no. 13, Colorado State Univ., Fort Collins, Colo.

78. Gordon, R.W. et al. 1969. Studies of a simple laboratory microecosystem: bacterial activities in a heterotrophic succession. Ecology 50(1): 86-100.

79. Morita, R.Y. 1966. Marine psychrophilic bacteria. Ann. Rev. Oceanogr. Mar. Biol. 4:105-121.

80. MacLeod, R.A. 1968. On the role of inorganic ions in the physiology of marine bacteria. In: Advances in microbiology of the sea (M.R. Droop and E. J. F. Wood, eds.). Academic Press, New York, New York.

81. Cooke, W.B. et al. 1960. Yeasts in polluted water and sewage. Mycol. 52:210-230.

82. Breed, R.S. et al. 1957. Bergey's manual of determinative bacteriology, 7th ed. The Williams and Wilkins Co., Baltimore, Md.

83. Skerman, V.B.D. 1967. A guide to the identification of the genera of bacteria, 2nd ed. The Williams and Wilkins Co., Baltimore, Md.

84. Wolff, J. 1966. Microflora of the Connecticut River in the Haddam Neck-Salmon River region. M.S. thesis, University of Connecticut.

85. Farrell, J. and A.H. Rose. 1967. Temperature effects on micro-organisms. In: Thermobiology (A.H. Rose, ed.), Academic Press, New York, N.Y.

86. Oppenheimer, C.H. and W. Drost-Hansen. 1960. A relationship between multiple temperature optima for biological systems and the properties of water. J. Bacteriol. 80:21-24.